ROOT

An Object-Oriented
Data Analysis Framework

Users Guide v0.7.2

March 2001

Comments to: rootdoc@root.cern.ch

The ROOT User's Guide:

Authors: René Brun/CERN, Fons Rademakers, Suzanne Panacek/FNAL, Damir Buskulic/Universite de Savoie/LAPP, Jörn Adamczewski/GSI, Marc Hemberger/GSI

Editor: Suzanne Panacek/FNAL

Special Thanks to: Philippe Canal/FNAL, Andrey Kubarovsky/FNAL

Preface

In late 1994, we decided to learn and investigate Object Oriented programming and C++ to better judge the suitability of these relatively new techniques for scientific programming. We knew that there is no better way to learn a new programming environment than to use it to write a program that can solve a real problem. After a few weeks, we had our first histogramming package in C++. A few weeks later we had a rewrite of the same package using the, at that time, very new template features of C++. Again, a few weeks later we had another rewrite of the package without templates since we could only compile the version with templates on one single platform using a specific compiler. Finally, after about four months we had a histogramming package that was faster and more efficient than the well-known FORTRAN based HBOOK a histogramming package. This gave us enough confidence in the new technologies to decide to continue the development. Thus was born ROOT.

Since its first public release at the end of 1995, ROOT has enjoyed an ever-increasing popularity. Currently it is being used in all major High Energy and Nuclear Physics laboratories around the world to monitor, to store and to analyze data. In the other sciences as well as the medical and financial industries, many people are using ROOT. We estimate the current user base to be around several thousand people.

In 1997, Eric Raymond analyzed in his paper "The Cathedral and the Bazaar" the development method that makes Linux such a success. The essence of that method is: "release early, release often and listen to your customers". This is precisely how ROOT is being developed. Over the last five years, many of our "customers" became co-developers. Here we would like to thank our main co-developers and contributors:

Masaharu Goto who wrote the CINT C++ interpreter. CINT has become an essential part of ROOT. Despite being 8 time zones ahead of us, we often have the feeling he is sitting in the room next door.

Valery Fine who ported ROOT to Windows and who also contributed largely to the 3-D graphics and geometry packages.

Nenad Buncic who developed the HTML documentation generation system and integrated the X3D viewer in ROOT.

Philippe Canal who developed the automatic compiler interface to CINT. In addition to a large number of contributions to many different parts of the system, Philippe is also the ROOT support coordinator at FNAL.

Suzanne Panacek who is the main author of this manual. Suzanne is also very active in preparing tutorials and giving lectures about ROOT.

Further, we would like to thank the following people for their many contributions, bug fixes, bug reports and comments:

Maarten Ballintijn, Stephen Bailey, Damir Buskulic, Federico Carminati, Mat Dobbs, Rutger v.d. Eijk, Anton Fokin, Nick van Eijndhoven, George Heintzelman, Marc Hemberger, Christian Holm Cristensen, Jacek M. Holeczek, Stephan Kluth, Marcel Kunze, Christian Lacunza, Matthew D. Langston, Michal Lijowski, Peter Malzacher, Dave Morrison, Eddy Offermann, Pasha Murat, Valeriy Onuchin, Victor Perevoztchikov, Sven Ravndal, Reiner Rohlfs, Gunther Roland, Andy Salnikov, Otto Schaile, Alexandre V. Vaniachine, Torre Wenaus and Hans Wenzel, and many more who have also contributed

You all helped in making ROOT a great experience.

Happy ROOTing!

Rene Brun & Fons Rademakers

Geneva, August 2000.

Table of Contents

1 Introduction

In the mid 1990's, René Brun and Fons Rademakers had many years of experience developing interactive tools and simulation packages. They had lead successful projects such as PAW, PIAF, and GEANT, and they knew the twenty-year-old FORTRAN libraries had reached their limits. Although still very popular, these tools could not scale up to the challenges offered by the Large Hadron Collider, where the data is a few orders of magnitude larger than anything seen before.

At the same time, computer science had made leaps of progress especially in the area of Object Oriented Design, and René and Fons were ready to take advantage of it.

ROOT was developed in the context of the NA49 experiment at CERN. NA49 has generated an impressive amount of data, around 10 Terabytes per run. This rate provided the ideal environment to develop and test the next generation data analysis.

One cannot mention ROOT without mentioning CINT its C++ interpreter. CINT was created by Masa Goto in Japan. It is an independent product, which ROOT is using for the command line and script processor.

ROOT was, and still is, developed in the "Bazaar style", a term from the book "The Cathedral and the Bazaar" by Eric S. Raymond. It means a liberal, informal development style that heavily leverages the diverse and deep talent of the user community. The result is that physicists developed ROOT for themselves, this made it specific, appropriate, useful, and over time refined and very powerful.

When it comes to storing and mining large amount of data, physics plows the way with its Terabytes, but other fields and industry follow close behind as they acquiring more and more data over time, and they are ready to use the true and tested technologies physics has invented. In this way, other fields and industries have found ROOT useful and they have started to use it also.

The development of ROOT is a continuous conversation between users and developers with the line between the two blurring at times and the users becoming co-developers.

In the bazaar view, software is released early and frequently to expose it to thousands of eager co-developers to pound on, report bugs, and contribute possible fixes. More users find more bugs, because more users add different ways of stressing the program. By now, after six years, many, many users have stressed ROOT in many ways, and it is quiet mature. Most likely, you will find the features you are looking for, and if you have found a hole, you are encouraged to participate in the dialog and post your suggestion or even implementation on roottalk, the ROOT mailing list.

The ROOT Mailing List

You can subscribe to roottalk, the ROOT Mailing list by registering at the ROOT web site: http://root.cern.ch/root/Registration.phtml.

This is a very active list and if you have a question, it is likely that it has been asked, answered, and stored in the archives. Please use the search engine to see if your question has already been answered before sending mail to root talk.

You can browse the roottalk archives at: http://root.cern.ch/root/roottalk/AboutRootTalk.html.

You can send your question without subscribing to: roottalk@root.cern.ch

Contact Information

This book was written by several authors. If you would like to contribute a chapter or add to a section, please contact us. This is the first and early release of this book, and there are still many omissions. However, we wanted to follow the ROOT tradition of releasing early and often to get feedback early and catch mistakes. We count on you to send us suggestions on additional topics or on the topics that need more documentation. Please send your comments, corrections, questions, and suggestions to rootdoc@root.cern.ch.

We attempt to give the user insight into the many capabilities of ROOT. The book begins with the elementary functionality and progresses in complexity reaching the specialized topics at the end.

The new user wanting a quick start and just a taste of ROOT should read the Introduction, and the chapters: Getting Started, Histograms, Graphs, and Fitting Histograms.

The user interested in learning and using ROOT should read the Introduction, and the chapters on CINT, Input/Output, Graphics and the Graphical User Interface, and Trees.

The user with some experience will be interested in the chapters on Graphics and the Graphical User Interface, Collection Classes, The Tutorials and Tests, and the Example Analysis.

The experienced user looking for special topics may find these chapters useful: Networking, Writing a Graphical User Interface, Threads, and PROOF: Parallel Processing.

Because this book was written by several authors, you may see some inconsistencies and a "change of voice" from one chapter to the next. We felt we could accept this in order to have the expert explain what they know best.

Conventions Used in This Book

We tried to follow a style convention for the sake of clarity. Here are the few styles we used.

To show source code in scripts or source files:

```
{
   cout << " Hello" << endl;
   float x = 3.;
   float y = 5.;
   int   i = 101;
   cout <<" x = "<<x<<" y = "<<y<<" i = "<<i<< endl;
}
```

To show the ROOT command line, we show the ROOT prompt without numbers. In the interactive system, the ROOT prompt has a line number (root [12]), for the sake of simplicity we left off the line number.

Bold monotype font indicates text for you to enter at verbatim.

```
root[] TLine l
root[] l.Print()
TLine  X1=0.000000 Y1=0.000000 X2=0.000000 Y2=0.000000
```

Italic bold monotype font indicates a global variable, for example ***`gDirectory`***.

We also used the italic bold font to ***`highlight the comments`*** in the code listing.

When a variable term is used, it is shown between angled brackets. In the example below the variable term <library> can be replaced with any library in the $ROOTSYS directory.

$ROOTSYS/<library>/inc

The Framework

ROOT is an object-oriented framework aimed at solving the data analysis challenges of high-energy physics. There are two key words in this definition, object oriented and framework. First, we explain what we mean by a framework and then why it is an object-oriented framework.

What is a Framework?

Programming inside a framework is a little like living in a city. Plumbing, electricity, telephone, and transportation are services provided by the city. In your house, you have interfaces to the services such as light switches, electrical outlets, and telephones. The details, for example the routing algorithm of the phone switching system, are transparent to you as the user. You do not care, your are only interested in using the phone to communicate with your collaborators to solve your domain specific problems.

Programming outside of a framework may be compared to living in the country. In order to have transportation and water, you will have to build a road and dig a well. To have services like telephone and electricity you will need to route the wires to your home. In addition, you cannot build some things yourself. For example, you cannot build a commercial airport on your patch of land. From a global perspective, it would make no sense for everyone to build their own airport. You see you will be very busy building the infrastructure (or framework) before you can use the phone to communicate with your collaborators and have a drink of water at the same time.

In software engineering, it is much the same way. In a framework the basic utilities and services, such as I/O and graphics, and are provided. In addition, ROOT being a HEP analysis framework, it provides a large selection of HEP specific utilities such as histograms and fitting. The drawback of a framework is that you are constrained to it, as you are constraint to use the routing algorithm provided by your telephone service. You also have to learn the framework interfaces, which in this analogy is the same as learning how to use a telephone.

If you are interested in doing physics, a good HEP framework will save you much work.

Below is a list of the more commonly used components of ROOT:

- Command Line Interpreter
- Histograms and Fitting
- Graphic User Interface widgets
- 2D Graphics
- I/O
- Collection Classes
- Script Processor

There are also less commonly used components, these are:

- 3D Graphics
- Parallel Processing (PROOF)
- Run Time Type Identification (RTTI)
- Socket and Network Communication
- Threads

Advantages of Frameworks

The benefits of frameworks can be summarized as follows:

- <u>Less code to write</u>: The programmer should be able to use and reuse the majority of the code. Basic functionality, such as fitting and histogramming are implemented and ready to use and customize.
- <u>More reliable and robust code:</u> Code inherited from a framework has already been tested and integrated with the rest of the framework.
- <u>More consistent and modular code</u>: Code reuse provides consistency and common capabilities between programs, no matter who writes them. Frameworks also make it easier to break programs into smaller pieces.
- <u>More focus on areas of expertise</u>: Users can concentrate on their particular problem domain. They don't have to be experts at writing user interfaces, graphics, or networking to use the frameworks that provide those services.

Why Object-Oriented?

Object-Oriented Programming offers considerable benefits compared to Procedure-Oriented Programming:

- <u>Encapsulation</u> enforces data abstraction and increases opportunity for reuse.

- Sub classing and inheritance make it possible to extend and modify objects.
- Class hierarchies and containment hierarchies provide a flexible mechanism for modeling real-world objects and the relationships among them.
- Complexity is reduced because there is little growth of the global state, the state is contained within each object, rather than scattered through the program in the form of global variables.
- Objects may come and go, but the basic structure of the program remains relatively static, increases opportunity for reuse of design.

Installing ROOT

The installation and building of ROOT is described in Appendix A: Install and Build ROOT. You can download the binaries (7 MB to 11 MB depending on the platform), or the source (about 3.4 MB). ROOT can be compiled by the GNU g++ compiler on most Unix platforms.

ROOT is currently running on the following platforms:

- `Intel x86 Linux (g++, egcs and KAI/KCC)`
- `Intel Itanium Linux (g++)`
- `HP HP-UX 10.x (HP CC and aCC, egcs1.2 C++ compilers)`
- `IBM AIX 4.1 (xlc compiler and egcs1.2)`
- `Sun Solaris for SPARC (SUN C++ compiler and egcs)`
- `Sun Solaris for x86 (SUN C++ compiler)`
- `Sun Solaris for x86 KAI/KCC`
- `Compaq Alpha OSF1 (egcs1.2 and DEC/CXX)`
- `Compaq Alpha Linux (egcs1.2)`
- `SGI Irix (g++ , KAI/KCC and SGI C++ compiler)`
- `Windows NT and Windows95 (Visual C++ compiler)`
- `Mac MkLinux and Linux PPC (g++)`
- `Hitachi HI-UX (egcs)`
- `LynxOS`
- `MacOS (CodeWarrior, no graphics)`

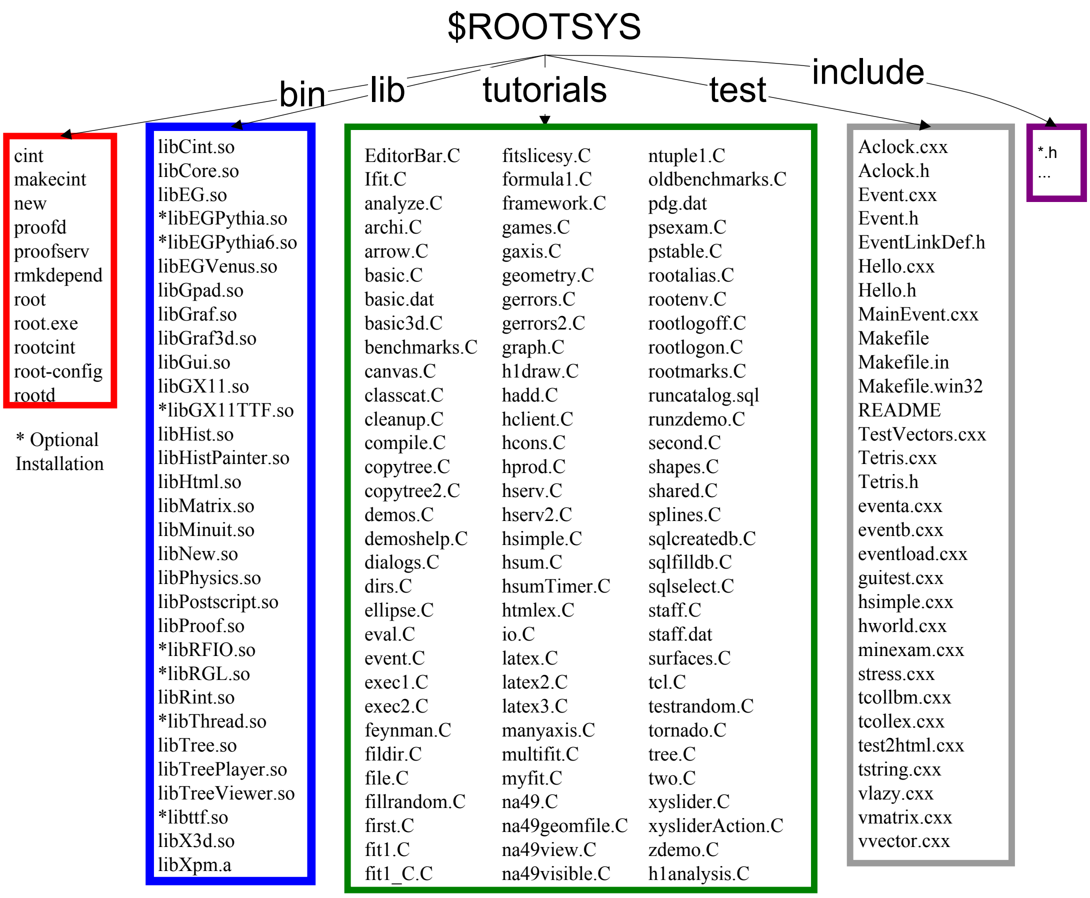
The Organization of the ROOT Framework

Now we know in abstract terms what the ROOT framework is, let's look at the physical directories and files that come with the installation of ROOT.

You may work on a platform where your system administrator has already installed ROOT. You will need to follow the specific development environment for your setup and you may not have write access to the directories. In any case, you will need an environment variable called `ROOTSYS`, which holds the path of the top directory.

```
> echo $ROOTSYS
/home/root
```

In the `ROOTSYS` directory are examples, executables, tutorials, header files, and if you opted to download the source it is also here. The directories of special interest to us are `bin`, `tutorials`, `lib`, `test`, and `include`. The diagram on the next page shows the contents of these directories.



$ROOTSYS/bin

The bin directory contains several executables.

- root shows the ROOT splash screen and calls root.exe.
- root.exe is the executable that root calls, if you use a debugger such as gdb, you will need to run root.exe directly.
- rootcint is the utility ROOT uses to create a class dictionary for CINT. You will see how this utility is used in the chapter: Trees
- rmkdepend is a modified version of makedepend that works for C++. It is used by the ROOT build system.
- root-config is a script returning the needed compile flags and libraries for projects that compile and link with ROOT.
- cint is the C++ interpreter executable that is independent of ROOT.
- makecint is the pure CINT version of rootcint. It is used to generate a dictionary. It is used by some of CINT's install scripts to generate dictionaries for external system libraries.
- proofd is a small daemon used to authenticate a user of ROOT's parallel processing capability (PROOF).
- proofserv is the actual PROOF process, which is started by proofd after a user, has successfully been authenticated.
- rootd is the daemon for remote ROOT file access (see TNetFile).

$ROOTSYS/lib

There are several ways to use ROOT, one way is to run the executable by typing root at the system prompt another way is to link with the ROOT libraries and make the ROOT classes available in your own program.

Here is a short description for each library, the ones marked with a * are only installed when the options specified them.

- libCint.so is the C++ interpreter (CINT).
- libCore.so is the Base classes
- libEG.so is the abstract event generator interface classes
- *libEGPythia.so is the Pythia5 event generator interface
- *libEGPythia6.so is the Pythia6 event generator interface
- libEGVenus.so is the Venus event generator interface
- libGpad.so is the pad and canvas classes which depend on low level graphics
- libGraf.so is the 2D graphics primitives (can be used independent of libGpad.so)
- libGraf3d.so is the3D graphics primitives
- libGui.so is the GUI classes (depend on low level graphics)
- libGX11.so is the low level graphics interface to the X11 system
- *libGX11TTF.so is an add on library to libGX11.so providing TrueType fonts
- libHist.so is the histogram classes
- libHistPainter.so is the histogram painting classes
- libHtml.so is the HTML documentation generation system
- libMatrix.so is the matrix and vector manipulation
- libMinuit.so - The MINUIT fitter
- libNew.so is the special global new/delete, provides extra memory checking and interface for shared memory (optional)
- libPhysics.so is the physics quantity manipulation classes (TLorentzVector, etc.)

- `libPostScript.so` is the PostScript interface
- `libProof.so` is the parallel ROOT Facility classes
- `*libRFIO.so` is the interface to CERN RFIO remote I/O system.
- `*libRGL.so` is the interface to OpenGL.
- `libRint.so` is the interactive interface to ROOT (provides command prompt).
- `*libThread.so` is the Thread classes.
- `libTree.so` is the `TTree` object container system.
- `libTreePlayer.so` is the `TTree` drawing classes.
- `libTreeViewer.so` is the graphical `TTree` query interface.
- `libX3d.so` is the X3D system used for fast 3D display.

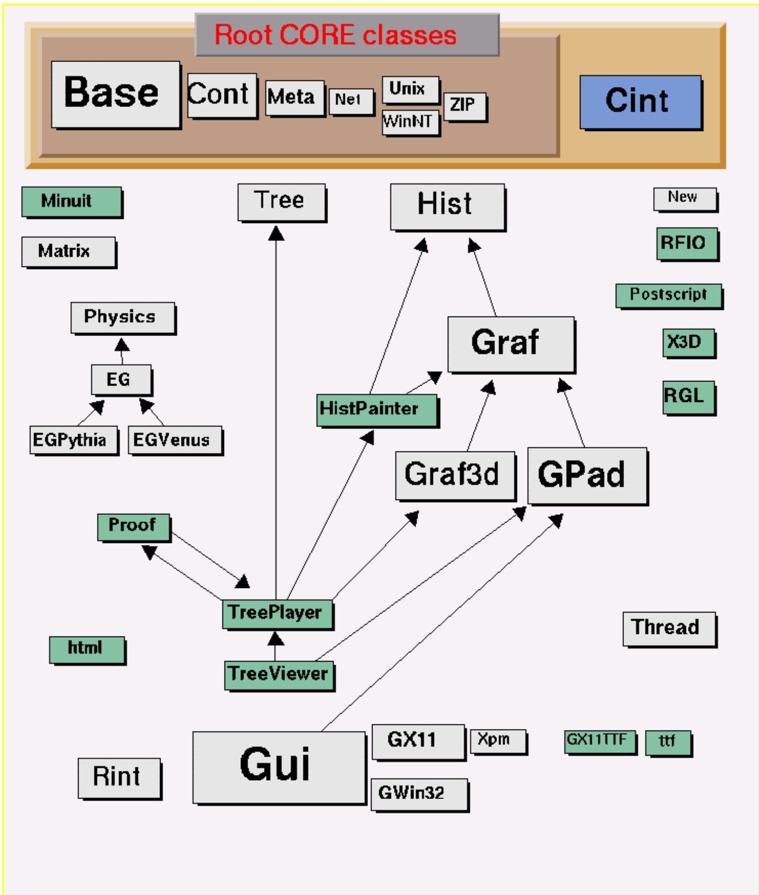
Library Dependencies

The libraries are designed and organized to minimize dependencies, such that you can include just enough code for the task at hand rather than having to include all libraries or one monolithic chunk.

The core library (`libCore.so`) contains the essentials; it needs to be included for all ROOT applications. In the diagram, you see that `libCore` is made up of Base classes, Container classes, Meta information classes, Networking classes, Operating system specific classes, and the ZIP algorithm used for compression of the ROOT files.

The CINT library (`libCint.so`) is also needed in all ROOT applications, but `libCint` can be used independently of `libCore`, in case you only need the C++ interpreter and not ROOT. That is the reason these two are separate.

A program referencing only `TObject` only needs `libCore` and `libCint`. This includes the ability to read and write ROOT objects, and there are no dependencies on graphics, or the GUI.



A batch program, one that does not have a graphic display, which creates, fills, and saves histograms and trees, only needs the core (`libCore` and `libCint`), `libHist` and `libTree`. If other libraries are needed, ROOT loads them dynamically. For example if the `TreeViewer` is used, `libTreePlayer` and all the libraries the `TreePlayer` box below has an arrow to, are loaded also. In this case: `GPad, Graf3d, Graf, HistPainter, Hist,` and `Tree`. The difference between `libHist` and `libHistPainter` is that the former needs to be explicitly linked and the latter will be loaded automatically at runtime when needed. In the diagram, the dark boxes outside of the core are automatically loaded libraries, and the light colored ones are not automatic. Of course, if one wants to access an automatic library directly, it has to be explicitly linked also.

An example of a dynamically linked library is `Minuit`. To create and fill histograms you need to link `libHist`. If the code has a call to fit the histogram, the "Fitter" will check if `Minuit` is already loaded and if not it will dynamically load it.

$ROOTSYS/tutorials

The tutorials directory contains many example scripts. They assume some basic knowledge of ROOT, and for the new user we recommend reading the chapters: **Histograms** and **Input/Output** before trying the examples. The more experienced user can jump to chapter The Tutorials and Tests to find more explicit and specific information about how to build and run the examples.

$ROOTSYS/test

The test directory contains a set of examples that represent all areas of the framework. When a new release is cut, the examples in this directory are compiled and run to test the new release's backward compatibility.

We see these source files:

- `hsimple.cxx` - Simple test program that creates and saves some histograms
- `MainEvent.cxx` - Simple test program that creates a ROOT Tree object and fills it with some simple structures but also with complete histograms. This program uses the files `Event.cxx`, `EventCint.cxx` and `Event.h`. An example of a procedure to link this program is in `bind_Event`. Note that the `Makefile` invokes the rootcint utility to generate the CINT interface `EventCint.cxx`.
- `Event.cxx` - Implementation for classes Event and Track
- `minexam.cxx` - Simple test program to test data fitting.
- `tcollex.cxx` - Example usage of the ROOT collection classes
- `tcollbm.cxx` - Benchmarks of ROOT collection classes
- `tstring.cxx` - Example usage of the ROOT string class
- `vmatrix.cxx` - Verification program for the `TMatrix` class
- `vvector.cxx` - Verification program for the `TVector` class
- `vlazy.cxx` - Verification program for lazy matrices.
- `hworld.cxx` - Small program showing basic graphics.
- `guitest.cxx` - Example usage of the ROOT GUI classes
- `Hello.cxx` - Dancing text example
- `Aclock.cxx` - Analog clock (a la X11 `xclock`)
- `Tetris.cxx` - The famous Tetris game (using ROOT basic graphics)

- `stress.cxx` - Important ROOT stress testing program.

The `$ROOTSYS/test` directory is a gold mine of ROOT-wisdom nuggets, and we encourage you to explore and exploit it. However, we recommend that the new user read the chapters:. The chapter Tutorials and Tests, has instructions on how to build all the programs and goes over the examples `Event` and `stress`.

$ROOTSYS/include

The `include` directory contains all the header files, this is especially important because the header files contain the class definitions.

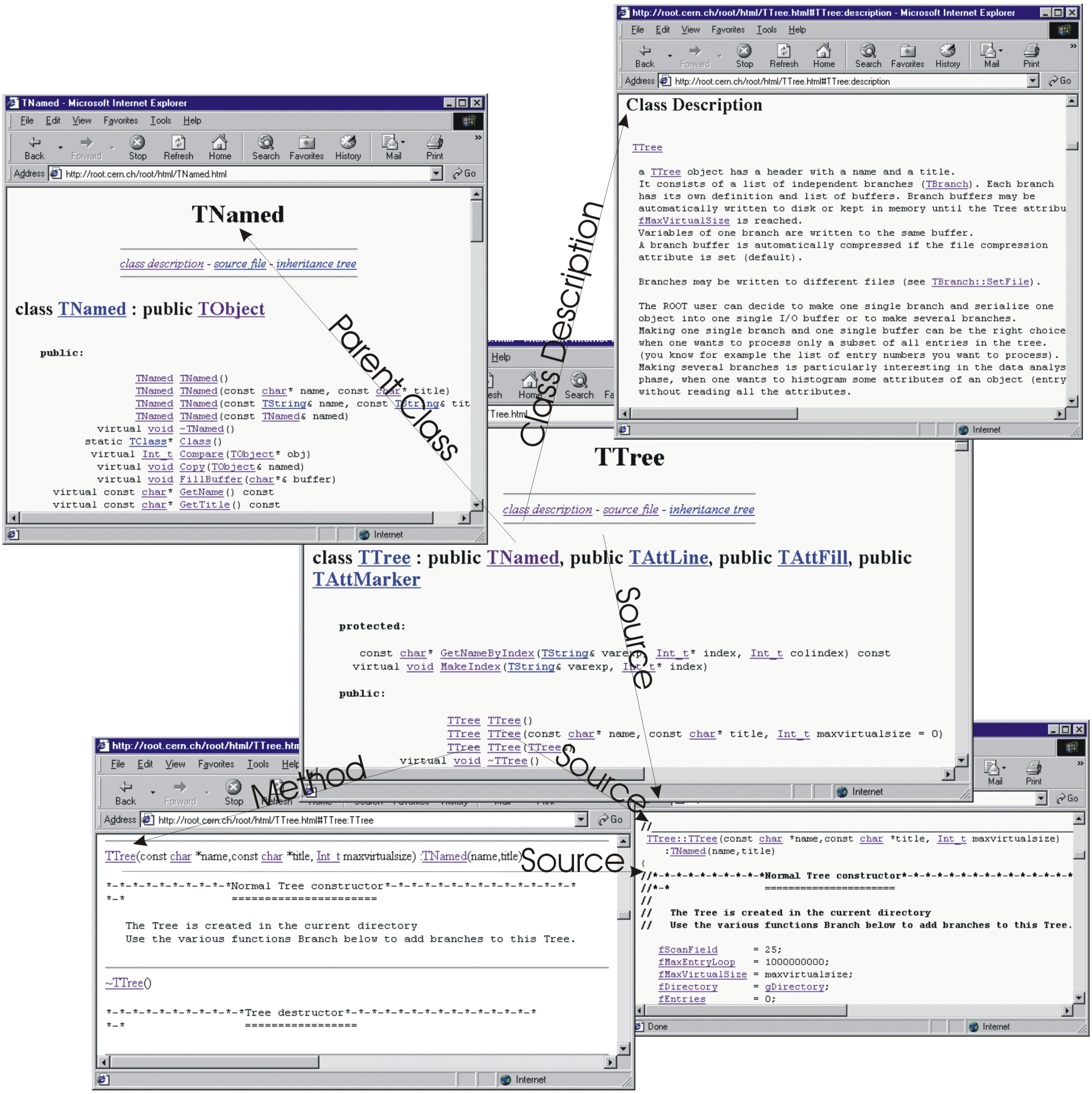
$ROOTSYS/<library>

The directories we explored above are available when downloading the binaries or the source. When downloading the source you also get a directory for each library with the corresponding header and source files. Each library directory contains an `inc` and a `src` subdirectory. To see what classes are in a library, you can check the `<library>/inc` directory for the list of class definitions. For example, the physics library contains these class definitions:

```
> ls -m  $ROOTSYS/physics/inc
CVS, LinkDef.h, TLorentzRotation.h, TLorentzVector.h,
TRotation.h, TVector2.h, TVector3.h
```

How to Find More Information

The ROOT web site has up to date documentation. The ROOT source code automatically generates this documentation, so each class is explicitly documented on its own web page, which is always up to date with the latest official release of ROOT. The class index web pages can be found at http://root.cern.ch/root/html/ClassIndex.html. Each page contains a class description, and an explanation of each method. It shows the class it was derived from and lets you jump to the parent class page by clicking on the class name. If you want more detail, you can even see the source. In addition to this, the site contains tutorials, "How To's", and a list of publications and example applications.



2 Getting Started

We begin by showing you how to use ROOT interactively. There are two examples to click through and learn how to use the GUI. We continue by using the command line, and explaining the coding conventions, global variables and the environment setup.

If you have not installed ROOT, you can do so by following the instructions in the appendix, or on the ROOT web site: http://root.cern.ch/root/Availability.html

Start and Quit a ROOT Session

To start ROOT you can type `root` at the system prompt. This starts up CINT the ROOT command line C/C++ interpreter, and it gives you the ROOT prompt (`root [0]`).

```
% root
  *******************************************
  *                                         *
  *        W E L C O M E  to  R O O T       *
  *                                         *
  *   Version   2.25/02      21 August 2000 *
  *                                         *
  *  You are welcome to visit our Web site  *
  *          http://root.cern.ch            *
  *                                         *
  *******************************************

CINT/ROOT C/C++ Interpreter version 5.14.47, Aug 12 2000
Type ? for help. Commands must be C++ statements.
Enclose multiple statements between { }.
root [0]
```

It is possible to launch ROOT with some command line options, as shown below:

```
% root -/?
Usage: root [-l] [-b] [-n] [-q] [file1.C ... fileN.C]
 Options:
   -b : run in batch mode without graphics
   -n : do not execute logon and logoff macros as
        specified in .rootrc
   -q : exit after processing command line script files
   -l : do not show the image logo (splash sceen)
```

–b: Run in batch mode, without graphics display. This mode is useful in case one does not want to set the DISPLAY or cannot do it for some reason.

–n: Usually, launching a ROOT session will execute a logon script and quitting will execute a logoff script. This option prevents the execution of these two scripts.

It is also possible to execute a script without entering a ROOT session. One simply adds the name of the script(s) after the ROOT command. Be warned: after finishing the execution of the script, ROOT will normally enter a new session.

–q: exit after processing command line script files. Retrieving previous commands and navigating on the Command Line.

ROOT's powerful C/C++ interpreter gives you access to all available ROOT classes, global variables, and functions via a command line. By typing C++ statements at the prompt, you can create objects, call functions, execute scripts, etc. For example:

```
root[] 1+sqrt(9)
(double)4.000000000000e+00
root[]for (int i = 0; i<5; i++) cout << "Hello" << i << endl
Hello 0
Hello 1
Hello 2
Hello 3
Hello 4
root[] .q
```

Exit ROOT

To quit the command line type `.q`.

```
root[] .q
```

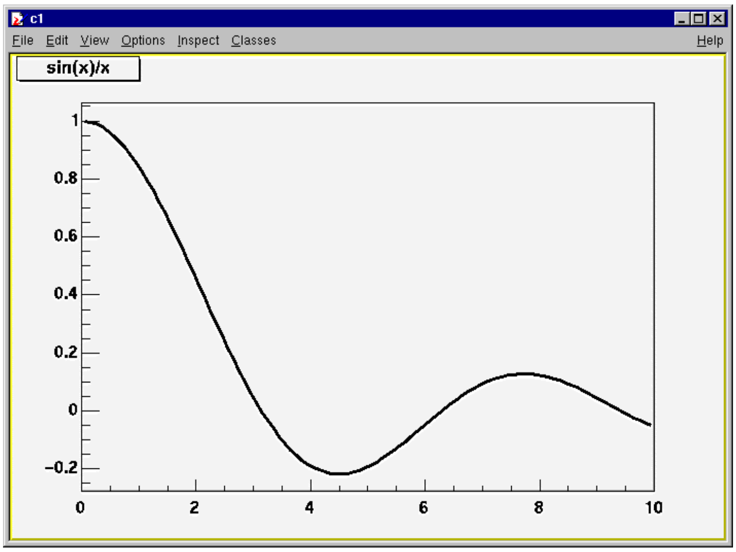
First Example: Using the GUI

In this example, we show how to use a function object, and change its attributes using the GUI. Again, start ROOT:

Note: The GUI on MS-Windows looks and works a little different from the one on UNIX. We are working on porting the new GUI class to Windows. Once they are available, the GUI will be changed to be identical to the one in UNIX. In this book, we used the UNIX GUI.

```
% root
…
root[] TF1 f1("func1", "sin(x)/x", 0, 10)
root[] f1.Draw()
```

You should see something like this:



Drawing a function is interesting, but it is not unique to a function. Evaluating and calculating the derivative and integral are what one would expect from a function. `TF1`, the function class defines these methods for us.

```
root [] f1.Eval(3)
(Double_t)4.70400026866224020e-02
root [] f1.Derivative(3)
(Double_t)(-3.45675056671992330e-01)
root [] f1.Integral(0,3)
(Double_t)1.84865252799946810e+00
root [] f1.Draw()
```

Note that by default `TF1::Paint`, the method that draws the function, computes 100 equidistant points to draw it. You can set the number of points to a higher value with the `TF1::SetNpx()` method:

```
root[] f1.SetNpx(2000);
```

Classes, Methods and Constructors

Object oriented programming introduces objects, which have data members and methods.

The line `TF1 f1("func1", "sin(x)/x", 0, 10)` creates an object named `f1` of the class `TF1` that is a one-dimensional function. The type of an object is called a class. The object is called an instance of a class. When a method builds an object, it is called a constructor.

```
TF1 f1("func1", "sin(x)/x", 0, 10)
```

In our constructor, we used `sin(x)/x`, which is the function to use, and 0 and 10 are the limits. The first parameter, `func1` is the name of the object `f1`. Most objects in ROOT have a name. ROOT maintains a list of objects that can be searched to find any object by its given name (in our example `func1`).

The syntax to call an object's method, or if one prefers, to make an object do something is:

```
object.method_name(parameters)
```

This is the usual way of calling methods in C++. The dot can be replaced by " `->`" if `object` is a pointer. In compiled code, the dot MUST be replaced by a "`->`" if `object` is a pointer.

```
object_ptr->method_name(parameters)
```

So now, we understand the two lines of code that allowed us to draw our function. `f1.Draw()` stands for “call the method `Draw` associated with the object `f1` of class `TF1`”. We will see the advantages of using objects and classes very soon.

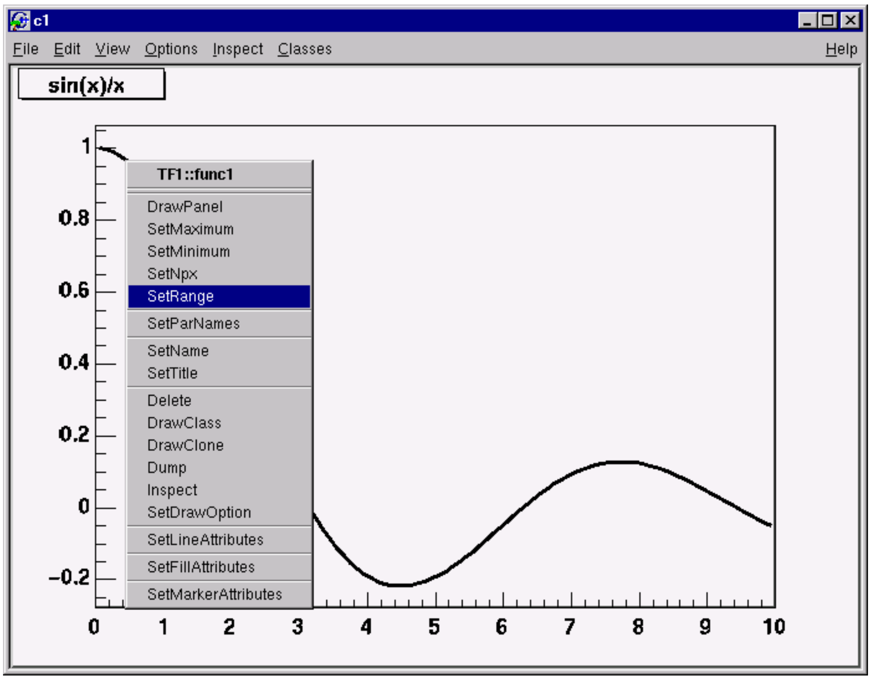
One point, the ROOT framework is an object oriented framework; however this does not prevent the user from calling plain functions. For example, most simple scripts have functions callable by the user.

User interaction

If you have quit the framework, try to draw the function `sin(x)/x` again. Now, we can look at some interactive capabilities. Every object in a window (which is called a Canvas) is in fact a graphical object in the sense that you can grab it, resize it, and change some characteristics with a mouse click.

For example, bring the cursor over the x-axis. The cursor changes to a hand with a pointing finger when it is over the axis. Now, left click and drag the mouse along the axis to the right. You have a very simple zoom.

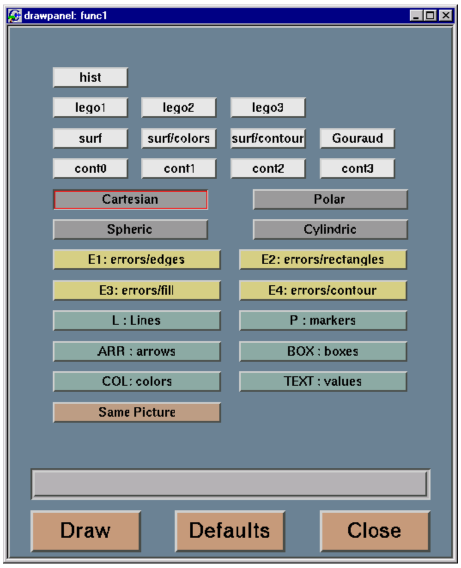
When you move the mouse over any object, you can get access to selected methods by pressing the right mouse button and obtaining a context menu. If you try this on the function (`TF1`), you will get a menu showing available methods. The other objects on this canvas are the title a `TPaveText`, the x and y-axis, which are `TAxis` objects, the frame a `TFrame`, and the canvas a `TCanvas`. Try clicking on these and observe the context menu with their methods.



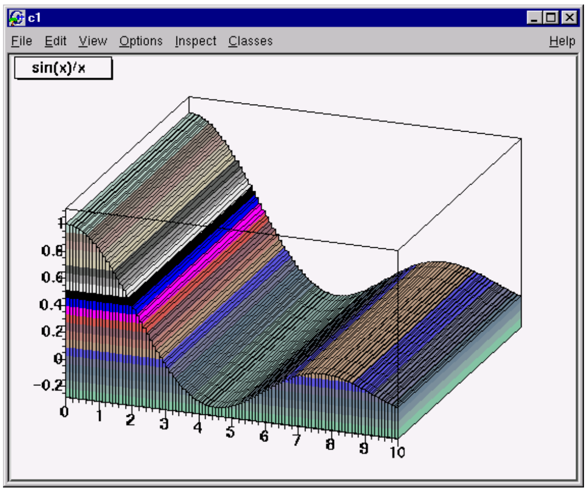
For the function, try for example to select the `SetRange` method and put -10, 10 in the dialog box fields. This is equivalent to executing the member function `f1.SetRange(-10,10)` from the command line prompt, followed by `f1.Draw()`.

Here are some other options you can try. For example, select the `DrawPanel` item of the popup menu.

You will see a panel like this:

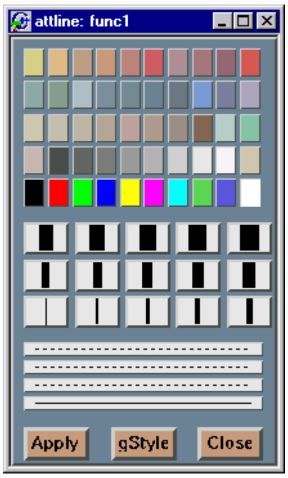


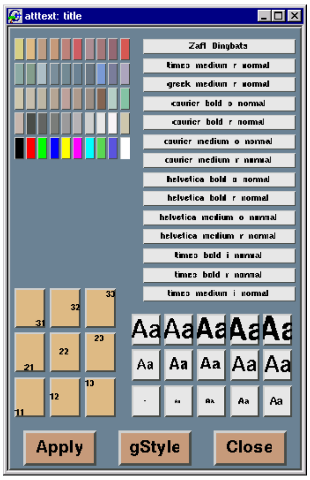
Try to resize the bottom slider and click Draw. You can zoom your graph. If you click on "lego2" and "Draw", you will see a 2D representation of your graph:

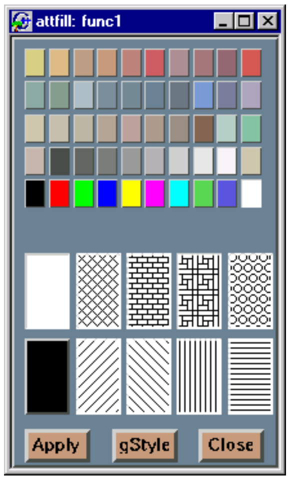


This 2D plot can be rotated interactively. Of course, ROOT is not limited to 1D graphs - it is possible to plot real 2D functions or graphs. There are numerous ways to change the graphical options/colors/fonts with the various methods available in the popup menu.

Line attributes ***Text attributes*** ***Fill attributes***







Once the picture suits your wishes, you may want to see the code you should put in a script to obtain the same result. To do that, choose the "Save as canvas.C" option in the "File" menu. This will generate a script showing the various options. Notice that you can also save the picture in PostScript or GIF format.

One other interesting possibility is to save your canvas in native ROOT format. This will enable you to open it again and to change whatever you like, since all the objects associated to the canvas (histograms, graphs) are saved at the same time.

Second Example: Building a Multi-pad Canvas

Let's now try to build a canvas (i.e. a window) with several pads. The pads are sub-windows that can contain other pads or graphical objects.

```
root[] TCanvas *MyC = new TCanvas("MyC","Test canvas",1)
root[] MyC->Divide(2,2)
```

Once again, we called the constructor of a class, this time the class `TCanvas`. The difference with the previous constructor call is that we want to build an object with a pointer to it.

Next, we call the method `Divide` of the `TCanvas` class (that is `TCanvas::Divide()`), which divides the canvas into four zones and sets up a pad in each of them.

```
root[] MyC->cd(1)
root[] f1->Draw()
```

Now, the function `f1` will be drawn in the first pad. All objects will now be drawn in that pad. To change the active pad, there are three ways:

Click on the middle button of the mouse on an object, for example a pad. This sets this pad as the active one

Use the method `TCanvas::cd` with the pad number, as was done in the example above:

```
root[] MyC->cd(3)
```

Pads are numbered from left to right and from top to bottom.

Each new pad created by `TCanvas::Divide` has a name, which is the name of the canvas followed by _1, _2, etc. For example to apply the method `cd()` to the third pad, you would write:

```
root[] MyC_3->cd()
```

The third pad will be selected since you called `TPad::cd()` for the object `MyC_3`. ROOT automatically found the pad that was named `MyC_3` when you typed it on the command line (see ROOT/CINT Extensions to C++).

The obvious question is: what is the relation between a canvas and a pad? In fact, a canvas is a pad that spans through an entire window. This is nothing else than the notion of inheritance. The `TPad` class is the parent of the `TCanvas` class.

The ROOT Command Line

We have briefly touched on how to use the command line, and you probably saw that there are different types of commands.

1.CINT commands start with "."

```
root [].?
//this command will list all the CINT commands
root [].l <filename>
//load [filename]
root [].x <filename>
//load [filename] and execute function [filename]
```

2.SHELL commands start with "`.!`" for example:

```
root [] .! ls
```

3. C++ commands follow C++ syntax (almost)

```
root [] TBrowser *b = new TBrowser()
```

CINT Extensions

We can see that some things are not standard C++. The CINT interpreter has several extensions. See the section ROOT/CINT Extensions to C++ in chapter CINT the C++ Interpreter

Helpful Hints for Command Line Typing

The interpreter knows all the classes, functions, variables, and user defined types. This enables ROOT to help the user complete the command line. For example we do not know yet anything about the `TLine` class. We can use the Tab feature to get help. Where <TAB> means type the <TAB> key. This lists all the classes starting with TL.

```
root [] l = new TL<TAB>
TLeaf
TLeafB
TLeafC
TLeafD
TLeafF
TLeafI
TLeafObject
TLeafS
TLine
TLatex
TLegendEntry
TLegend
TLink
TList
TListIter
TLazyMatrix
TLazyMatrixD
```

This lists the different constructors and parameters for `TLine`.

```
root [] l = new TLine(<TAB>
TLine TLine()
TLine TLine(Double_t x1, Double_t y1, Double_t x2, Double_t y2)
TLine TLine(const TLine& line)
```

Multi-line Commands

You can use the command line to execute multi-line commands. To begin a multi-line command you must type a single left curly bracket {, and to end it you must type a single right curly bracket }.

For example:

```
root[] {
end with '}'> Int_t j = 0;
end with '}'> for (Int_t i = 0; i < 3; i++)
end with '}'> {
end with '}'> j= j + i;
end with '}'> cout <<"i = " <<i<<", j = " <<j<<endl;
end with '}'> }
end with '}'> }
i = 0, j = 0
i = 1, j = 1
i = 2, j = 3
```

It is more convenient to edit scripts than the command line, and if your multi line commands are getting unmanageable you may want to start a script instead.

Conventions

In this paragraph, we will explain some of the conventions used in ROOT source and examples.

Coding Conventions

From the first days of ROOT development, it was decided to use a set of coding conventions. This allows a consistency throughout the source code. Learning these will help you identify what type of information you are dealing with and enable you to understand the code better and quicker. Of course, you can use whatever convention you want but if you are going to submit some code for inclusion into the ROOT sources you will need to use these. These are the coding conventions:

- Classes begin with T: `TTree, TBrowser`
- Non-class types end with _t: `Int_t`
- Data members begin with f: `fTree`
- Member functions begin with a capital: `Loop()`
- Constants begin with k: `kInitialSize, kRed`
- Global variables begin with g: `gEnv`
- Static data members begin with fg: `fgTokenClient`
- Enumeration types begin with E: `EColorLevel`
- Locals and parameters begin with a lower case: `nbytes`
- Getters and setters begin with Get and Set: `SetLast()`, `GetFirst()`

Machine Independent Types

Different machines may have different lengths for the same type. The most famous example is the `int` type. It may be 16 bits on some old machines and 32 bits on some newer ones.

To ensure the size of your variables, use these pre defined types in ROOT:

- `Char_t` Signed Character 1 byte
- `Uchar_t` Unsigned Character 1 byte
- `Short_t` Signed Short integer 2 bytes
- `UShort_t` Unsigned Short integer 2 bytes
- `Int_t` Signed integer 4 bytes
- `UInt_t` Unsigned integer 4 bytes
- `Long_t` Signed long integer 8 bytes
- `ULong_t` Unsigned long integer 8 bytes
- `Float_t` Float 4 bytes
- `Double_t` Float 8 bytes
- `Bool_t` Boolean (0=false, 1=true)

If you do not want to save a variable on disk, you can use `int` or `Int_t`, the result will be the same and the interpreter or the compiler will treat them in exactly the same way.

TObject

In ROOT, almost all classes inherit from a common base class called `TObject`. This kind of architecture is also used in the Java language. The `TObject` class provides default behavior and protocol for all objects in the ROOT system. The main advantage of this approach is that it enforces the common behavior of the derived classes and consequently it ensures the consistency of the whole system.

`TObject` provides protocol, i.e. (abstract) member functions, for:

- Object I/O (`Read(), Write()`)
- Error handling (`Warning(), Error(), SysError(), Fatal()`)
- Sorting (`IsSortable(), Compare(), IsEqual(), Hash()`)
- Inspection (`Dump(), Inspect()`)
- Printing (`Print()`)
- Drawing (`Draw(), Paint(), ExecuteEvent()`)
- Bit handling (`SetBit(), TestBit()`)
- Memory allocation (`operator new and delete, IsOnHeap()`)
- Access to meta information (`IsA(), InheritsFrom()`)
- Object browsing (`Browse(), IsFolder()`)

Global Variables

ROOT has a set of global variables that apply to the session. For example, ***gDirectory*** always holds the current directory, and ***gStyle*** holds the current style. All global variables begin with "g" followed by a capital letter.

gROOT

The single instance of TROOT is accessible via the global ***gROOT*** and holds information relative to the current session. By using the ***gROOT*** pointer you get the access to basically every object created in a ROOT program. The TROOT object has several lists pointing to the main ROOT objects.

ROOT's Housekeeping Lists

During a ROOT session, the system keeps a series of lists to maintain the environment. These can be accessed with the ***gROOT*** object. They are:

```
gROOT->GetListOfClasses()
gROOT->GetListOfColors()
gROOT->GetListOfTypes()
gROOT->GetListOfGlobals()
gROOT->GetListOfGlobalFunctions()
gROOT->GetListOfFiles()
gROOT->GetListOfMappedFiles()
gROOT->GetListOfSockets()
gROOT->GetListOfCanvases()
gROOT->GetListOfStyles()
gROOT->GetListOfFunctions()
gROOT->GetListOfSpecials() // for example graphical cuts
gROOT->GetListOfGeometries()
gROOT->GetListOfBrowsers()
gROOT->GetListOfMessageHandlers()
```

These methods return a `TSeqCollection`, meaning a collection of objects, and they can be used to do list operations such as finding an object, or traversing the list and calling a method for each of the members. See the `TCollection` class description for the full set of methods supported for a collection.

For example, to find a canvas called `c1`:

```
root[] gROOT->GetListOfCanvases()->FindObject("c1")
```

This returns a pointer to a `TObject,` and before you can use it as a canvas you will need cast it to a `TCanvas*`.

gFile

gFile is the pointer to the current opened file.

gDirectory

gDirectory is a pointer to the current directory. The concept and role of a directory is explained in chapter **Input/Output**.

gPad

A graphic object is always drawn on the active pad. It is convenient to access the active pad, no matter what it is. For that we have ***gPad*** that is always pointing to the active pad. For example, if you want to change the fill color of the active pad to blue, but you do not know its name, you can use ***gPad***.

```
root[] gPad->SetFillColor(38)
```

To get the list of colors, if you have an open canvas, click in the "View" menu, selecting the "Colors" entry.

gRandom

gRandom is a pointer to the current random number generator. By default, it points to a `TRandom` object. Setting the seed to 0 implies that the seed will be generated from the time. Any other value will be used as a constant.

The following basic random distributions are provided:

```
Gaus( mean, sigma)
Rndm()
Landau(mean, sigma)
Poisson(mean)
Binomial(ntot,prob)
```

You can customize your ROOT session by replacing the random number generator. You can delete ***gRandom*** and recreate it with your own:

```
root[] delete gRandom;
root[] gRandom = new TRandom3(0); //seed=0
```

`TRandom3` derives from `TRandom` and is a very fast generator with higher periodicity.

gEnv

gEnv is the global variable (of type `TEnv`) with all the environment settings for the current session. This variable is set by reading the contents of a `.rootrc` file at the beginning of the session. See "Environment Setup" below for more information.

History File

You can use the up and down arrow at the command line, to access the previous and next command. The commands are recorded in the history file `$HOME/.root_hist`. It contains the last 100 commands. It is a text file, and you can edit and cut and paste from it.

You can specify the history file in the system.rootrc (see below) file, by setting the `Rint.History` option. You can also turn off the command logging in the `system.rootrc` file with the option: `Rint.History: -`

Environment Setup

The behavior of a ROOT session can be tailored with the options in the `rootrc` file. At start-up, ROOT looks for a `rootrc` file in the following order:

- `./.rootrc` ***//local directory***
- `$HOME/.rootrc` ***//user directory***
- `$ROOTSYS/system.rootrc` ***//global ROOT directory***

If more than one `rootrc` file is found in the search paths above, the options are merged, with precedence local, user, global.

While in a session, to see current settings, you can do

```
root[] gEnv->Print()
```

The `rootrc` file typically looks like:

```
# Path used by dynamic loader to find shared libraries
Unix.*.Root.DynamicPath:  .:~/rootlibs:$ROOTSYS/lib
Unix.*.Root.MacroPath:    .:~/rootmacros:$ROOTSYS/macros

# Path where to look for TrueType fonts
Unix.*.Root.UseTTFonts:     true
Unix.*.Root.TTFontPath:
…
# Activate memory statistics
Rint.Root.MemStat:       1
Rint.Load:               rootalias.C
Rint.Logon:              rootlogon.C
Rint.Logoff:             rootlogoff.C
…
Rint.Canvas.MoveOpaque:  false
Rint.Canvas.HighLightColor: 5
```

The various options are explained in `$ROOTSYS/.rootrc`.

The `.rootrc` file contents are combined. For example, if the flag to use true type fonts is set to true in one of the `system.rootrc` files, you have to explicitly overwrite it and set it to false. Removing the `UseTTFonts` statement in the local `.rootrc` file will not disable true fonts.

The Script Path

ROOT looks for scripts in the path specified in the `rootrc` file in the `Root.Macro.Path` variable. You can expand this path to hold your own directories.

Logon and Logoff Scripts

The `rootlogon.C` and `rootlogoff.C` files are script loaded and executed at start-up and shutdown. The `rootalias.C` file is loaded but not executed. It typically contains small utility functions. For example, the `rootalias.C` script that comes with the ROOT distributions and is in the `$ROOTSYS/tutorials` defines the function `edit(char *file)`. This allows the user to call the editor from the command line. This particular function will start the VI editor if the environment variable `EDITOR` is not set.

```
root [0] edit("c1.C")
```

For more details, see `$ROOTSYS/tutorials/rootalias.C`.

Tracking Memory Leaks

You can track memory usage and detect leaks by monitoring the number of objects that are created and deleted (see `TObjectTable`). To use this facility, edit the file `.rootrc` if you have this file or `$ROOTSYS/system.rootrc` and edit or add the two following lines:

```
Root.MemStat:            1
Root.ObjectStat:         1
```

In your code, or on the command line you can type the line:

```
gObjectTable->Print();
```

This line will print the list of active classes and the number of instances for each class. By comparing consecutive print outs, you can see objects that you forgot to delete.

Note that this method cannot show leaks coming from the allocation of non-objects or classes unknown to ROOT.

Converting HBOOK/PAW files

ROOT has a utility called `h2root` that you can use to convert your HBOOK/PAW histograms or ntuples files into ROOT files. To use this program, you type the shell script command:

```
    h2root  <hbookfile>  <rootfile>
```

If you do not specify the second parameter, a file name is automatically generated for you. If `hbookfile` is of the form `file.hbook`, then the ROOT file will be called `file.root`.

This utility converts HBOOK histograms into ROOT histograms of the class `TH1F`. HBOOK profile histograms are converted into ROOT profile histograms (see class `TProfile`). HBOOK row-wise and column-wise ntuples are automatically converted to ROOT Trees (see the chapter on Trees). Some HBOOK column-wise ntuples may not be fully converted if the columns are an array of fixed dimension(e.g. `var[6]`) or if they are a multi-dimensional array.

HBOOK integer identifiers are converted into ROOT named objects by prefixing the integer identifier with the letter "`h`" if the identifier is a positive integer and by `"h_"` if it is a negative integer identifier.

In case of row-wise or column-wise ntuples, each column is converted to a branch of a tree.

Note that `h2root` is able to convert HBOOK files containing several levels of sub-directories.

Once you have converted your file, you can look at it and draw histograms or process ntuples using the ROOT command line. An example of session is shown below:

```
// this connects the file hbookconverted.root
root[] TFile f("hbookconverted.root");

//display histogram named h10 (was HBOOK id 10)
root[] h10.Draw();

//display column "var" from ntuple h30
root[] h30.Draw("var");
```

You can also use the ROOT browser (see TBrowser) to inspect this file.

The chapter on trees explains how to read a Tree. ROOT includes a function `TTree::MakeClass` to automatically generate the code for a skeleton analysis function (see the chapter Example Analysis).

In case one of the ntuple columns has a variable length (e.g. `px(ntrack)`), `h.Draw("px")` will histogram the `px` column for all tracks in the same histogram. Use the script quoted above to generate the skeleton function and create/fill the relevant histogram yourself.

3 Histograms

This chapter covers the functionality of the histogram classes. We begin with an overview of the histogram classes and their inheritance relationship. Then we give instructions on the histogram features.

We have put this chapter ahead of the graphics chapter so that you can begin working with histograms as soon as possible. Some of the examples have graphics commands that may look unfamiliar to you. These are covered in the chapter Graphics and the Graphical User Interface .

The Histogram Classes

ROOT supports the following histogram types:

1-D histograms:

- `TH1C`: are histograms with one byte per channel. Maximum bin content = 255
- `TH1S`: are histograms with one short per channel. Maximum bin content = 65,535
- `TH1F`: are histograms with one float per channel. Maximum precision 7 digits
- `TH1D`: are histograms with one double per channel. Maximum precision 14 digits

2-D histograms:

- `TH2C`: are histograms with one byte per channel. Maximum bin content = 255
- `TH2S`: are histograms with one short per channel. Maximum bin content = 65535
- `TH2F`: are histograms with one float per channel. Maximum precision 7 dig
- `TH2D`: are histograms with one double per channel. Maximum precision 14 digits

3-D histograms:

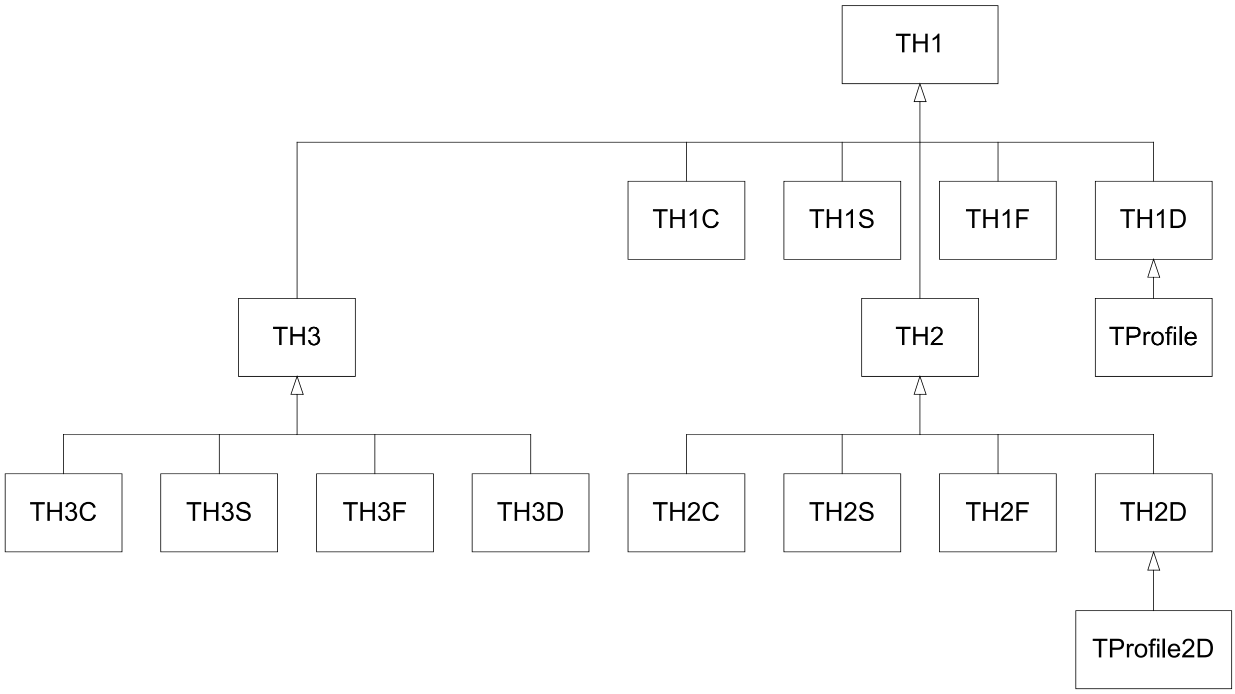
- `TH3C`: are histograms with one byte per channel. Maximum bin content = 255
- `TH3S`: are histograms with one short per channel. Maximum bin content = 65535
- `TH3F`: are histograms with one float per channel. Maximum precision 7 digits
- `TH3D`: are histograms with one double per channel. Maximum precision 14 digits

Profile histograms:

- `TProfile`: one dimensional profiles
- `TProfile2D`: two dimensional profiles

Profile histograms are used to display the mean value of Y and its RMS for each bin in X. Profile histograms are in many cases an elegant replacement of two-dimensional histograms. The inter-relation of two measured quantities X and Y can always be visualized with a two-dimensional histogram or scatter-plot. If Y is an unknown but single-valued approximate function of X, it will have greater precisions in a profile histogram than in a scatter plot.

All histogram classes are derived from the base class `TH1`. This image shows the class hierarchy of the histogram classes.



The `TH*C` classes also inherit from the array class `TArrayC`.
The `TH*S` classes also inherit from the array class `TArrayS`.
The `TH*F` classes also inherit from the array class `TArrayF`.
The `TH*D` classes also inherit from the array class `TarrayD`.

The histogram classes have a rich set of methods. Below is a list of what one can do with the histogram classes.

Creating Histograms

Histograms are created with constructors:

```
TH1F *h1 = new TH1F("h1","h1 title",100,0,4.4);
TH2F *h2 = new TH2F("h2","h2 title",40,0,4,30,-3,3);
```

The parameters to the `TH1` constructor are: the name of the histogram, the title, the number of bins, the x minimum, and x maximum.

Histograms may also be created by:

- Calling the `Clone` method of an existing histogram (see below)
- Making a projection from a 2-D or 3-D histogram (see below)
- Reading a histogram from a file

When a histogram is created, a reference to it is automatically added to the list of in-memory objects for the current file or directory. This default behavior can be disabled for an individual histogram or for all histograms by setting a global switch.

Here is the syntax to set the directory of a histogram:

```
// to set the in-memory directory for h the current histogram
h->SetDirectory(0);
// global switch to disable
TH1::AddDirectory(kFALSE);
```

When the histogram is deleted, the reference to it is removed from the list of objects in memory. In addition, when a file is closed, all histograms in memory associated with this file are automatically deleted. See chapter **Input/Output**.

Fixed or Variable Bin Size

All histogram types support fixed or variable bin sizes. 2-D histograms may have fixed size bins along X and variable size bins along Y or vice-versa. The functions to fill, manipulate, draw, or access histograms are identical in both cases.

To create a histogram with variable bin size one can use this constructor:

```
TH1(const char *name,const char *title,Int_t nbins,Float_t
*xbins)
```

The parameters to this constructor are:

- `title`: histogram title
- `nbins`: number of bins
- `xbins`: array of low-edges for each bin. This is an array of size nbins+1

Each histogram always contains three `TAxis` objects: `fXaxis`, `fYaxis`, and `fZaxis`. To access the axis parameters first get the axis from the histogram, and then call the `TAxis` access methods.

```
TAxis *xaxis = h->GetXaxis();
Double_t binCenter = xaxis->GetBinCenter(bin);
```

See class `TAxis` for a description of all the access methods. The axis range is always stored internally in double precision.

Bin numbering convention

For all histogram types: `nbins`, `xlow`, `xup`

Bin# 0 contains the underflow.
Bin# 1 contains the first bin with low-edge (`xlow` INCLUDED).
The second to last bin (bin# `nbins`) contains the upper-edge (`xup` EXCLUDED).
The Last bin (bin# `nbins+1)` contains the overflow.

In case of 2-D or 3-D histograms, a "global bin" number is defined. For example, assuming a 3-D histogram with `binx`, `biny`, `binz`, the function returns a global/linear bin number.

```
Int_t bin = h->GetBin(binx,biny,binz);
```

This global bin is useful to access the bin information independently of the dimension.

Re-binning

At any time, a histogram can be re-binned via the `TH1::Rebin method`. It returns a new histogram with the re-binned contents. If bin errors were stored, they are recomputed during the re-binning.

Filling Histograms

A histogram is typically filled with statements like:

```
h1->Fill(x);
h1->Fill(x,w); //with weight
h2->Fill(x,y);
h2->Fill(x,y,w);
h3->Fill(x,y,z);
h3->Fill(x,y,z,w);
```

The `Fill` method computes the bin number corresponding to the given x, y or z argument and increments this bin by the given weight. The `Fill` method returns the bin number for 1-D histograms or global bin number for 2-D and 3-D histograms. If `TH1::Sumw2` has been called before filling, the sum of squares is also stored.

One can also increment a bin number directly by calling `TH1::AddBinContent`. Replace the existing content via `TH1::SetBinContent`, and access the bin content of a given bin via `TH1::GetBinContent`.

```
Double_t binContent = h->GetBinContent(bin);
```

Automatic Re-binning Option

By default, the number of bins is computed using the range of the axis. You can change this to automatically re-bin by setting the automatic re-binning option:

```
h->SetBit(TH1::kCanRebin);
```

Once this is set, the `Fill` method will automatically extend the axis range to accommodate the new value specified in the `Fill` argument. The method used is to double the bin size until the new value fits in the range, merging bins two by two.

This automatic binning options is extensively used by the `TTree::Draw` function when drawing histograms of variables in `TTrees` with an unknown range. The automatic binning option is supported for 1-D, 2-D and 3-D histograms.

During filling, some statistics parameters are incremented to compute the mean value and root mean square with the maximum precision. In case of histograms of type `TH1C`, `TH1S, TH2C, TH2S, TH3C, TH3S` a check is made that the bin contents do not exceed the maximum positive capacity

(127 or 65535). Histograms of all types may have positive or/and negative bin contents.

Random Numbers and Histograms

`TH1::FillRandom` can be used to randomly fill a histogram using the contents of an existing `TF1` function or another `TH1` histogram (for all dimensions). For example, the following two statements create and fill a histogram 10000 times with a default Gaussian distribution of mean 0 and sigma 1:

```
TH1F h1("h1","histo from a gaussian",100,-3,3);
h1.FillRandom("gaus",10000);
```

`TH1::GetRandom` can be used to return a random number distributed according the contents of a histogram.

To fill a histogram following the distribution in an existing histogram you can use the second signature of `TH1::FillRandom`.

This code snipped assumes that `h` is an existing histogram (`TH1`).

```
root [] TH1F h2("h2","Random Histo",100,-3,3);
root [] h2->FillRandom(h,1000);
```

The distribution contained in the histogram h (`TH1`) is integrated over the channel contents. It is normalized to 1. Getting one random number implies:

- Generating a random number between 0 and 1 (say `r1`)
- Find the bin in the normalized integral for r1
- Fill histogram channel

The second parameter (1000) indicates how many random numbers are generated.

Adding, Dividing, and Multiplying

Many types of operations are supported on histograms or between histograms:

- Addition of a histogram to the current histogram
- Additions of two histograms with coefficients and storage into the current histogram
- Multiplications and Divisions are supported in the same way as additions.
- The Add, Divide and Multiply functions also exist to add, divide or multiply a histogram by a function.

If a histogram has associated error bars (`TH1::Sumw2` has been called), the resulting error bars are also computed assuming independent histograms. In case of divisions, binomial errors are also supported.

Projections

One can:

- Make a 1-D projection of a 2-D histogram or Profile. See functions `TH2::ProjectionX, TH2::ProjectionY, TH2::ProfileX, TH2::ProfileY, TProfile::ProjectionX, TProfile2D::ProjectionXY`
- Make a 1-D, 2-D or profile out of a 3-D histogram see functions `TH3::ProjectionZ, TH3::Project3D.`

One can fit these projections via: `TH2::FitSlicesX, TH2::FitSlicesY, TH3::FitSlicesZ.`

Drawing Histograms

When you call the `Draw` method of a histogram (`TH1::Draw`) for the first time, it creates a `THistPainter` object and saves a pointer to painter as a data member of the histogram. The `THistPainter` class specializes in the drawing of histograms. It is separate from the histogram so that one can have histograms without the graphics overhead, for example in a batch program. The choice to give each histogram have its own painter rather than a central singleton painter, allows two histograms to be drawn in two threads without overwriting the painter's values.

When a displayed histogram is filled again, you do not have to call the Draw method again. The image is refreshed the next time the pad is updated. A pad is updated after one of these three actions:

- A carriage control on the ROOT command line
- A click inside the pad
- A call to `TPad::Update`

By default, a call to `TH1::Draw` clears the pad of all objects before drawing the new image of the histogram. You can use the `"SAME"` option to leave the previous display in tact and superimpose the new histogram. The same histogram can be drawn with different graphics options in different pads.

When a displayed histogram is deleted, its image is automatically removed from the pad.

To create a copy of the histogram when drawing it, you can use `TH1::DrawClone`. This will clone the histogram and allow you to change and delete the original one without affecting the clone.

Setting the Style

Histograms use the current style **`gStyle`**, which is the global object of class `TStyle`. To change the current style for histograms, the `TStyle` class provides a multitude of methods ranging from setting the fill color to the axis tick marks. Here are a few examples:

```
void SetHistFillColor(Color_t color = 1)
void SetHistFillStyle(Style_t styl = 0)
void SetHistLineColor(Color_t color = 1)
void SetHistLineStyle(Style_t styl = 0)
void SetHistLineWidth(Width_t width = 1)
```

When you change the current style and would like to propagate the change to a previously created histogram you can call `TH1::UseCurrentStyle`. You will need to call `UseCurrentStyle` on each histogram.

When reading many histograms from a file and you wish to update them to the current style you can use `gROOT::ForceStyle` and all histograms read after this call will be updated to use the current style (also see the chapter Graphics and Graphic User Interfaces).

When a histogram is automatically created as a result of a `TTree::Draw`, the style of the histogram is inherited from the tree attributes and the current style is ignored. The tree attributes are the ones set in the current `TStyle` at the time the tree was created. Currently there is no way to force an existing tree to use the current style, but this feature will be added shortly.

Draw Options

The following draw options are supported on all histogram classes:

- "AXIS": Draw only the axis
- "HIST": Draw only the histogram outline (if the histogram has errors, they are not drawn)
- "SAME": Superimpose on previous picture in the same pad
- "CYL": Use cylindrical coordinates
- "POL": Use polar coordinates
- "SPH": Use spherical coordinates
- "PSR": Use pseudo-rapidity/phi coordinates
- "LEGO": Draw a lego plot with hidden line removal
- "LEGO1": Draw a lego plot with hidden surface removal
- "LEGO2": Draw a lego plot using colors to show the cell contents
- "SURF": Draw a surface plot with hidden line removal
- "SURF1": Draw a surface plot with hidden surface removal
- "SURF2": Draw a surface plot using colors to show the cell contents
- "SURF3": Same as SURF with a contour view on the top
- "SURF4": Draw a surface plot using Gouraud shading

The following options are supported for 1-D histogram classes:

- "AH": Draw the histogram, but not the axis labels and tick marks
- "B": Draw a bar chart
- "C": Draw a smooth curve through the histogram bins
- "E": Draw the error bars
- "E0": Draw the error bars including bins with 0 contents
- "E1": Draw the error bars with perpendicular lines at the edges
- "E2": Draw the error bars with rectangles
- "E3": Draw a fill area through the end points of the vertical error bars
- "E4": Draw a smoothed filled area through the end points of the error bars
- "L": Draw a line through the bin contents
- "P": Draw a (Poly) marker at each bin using the histogram's current marker style
- "*H": Draw histogram with a * at each bin

The following options are supported for 2-D histogram classes:

- "ARR": Arrow mode. Shows gradient between adjacent cells
- "BOX": Draw a box for each cell with surface proportional to contents
- "COL": Draw a box for each cell with a color scale varying with contents
- "COLZ": Same as "`COL`" with a drawn color palette
- "CONT": Draw a contour plot (same as `CONT0`)
- "CONTZ": Same as "`CONT`" with a drawn color palette
- "CONT0": Draw a contour plot using surface colors to distinguish contours
- "CONT1": Draw a contour plot using line styles to distinguish contours
- "CONT2": Draw a contour plot using the same line style for all contours
- "CONT3": Draw a contour plot using fill area colors

- "CONT4": Draw a contour plot using surface colors (SURF option at theta = 0)
- "LIST": Generate a list of `TGraph` objects for each contour
- "FB": To be used with LEGO or SURFACE, suppress the Front-Box
- "BB": To be used with LEGO or SURFACE, suppress the Back-Box
- "SCAT": Draw a scatter-plot (default)
- "Z": The "Z" option can be specified with the options : BOX, COL, CONT, SURF, and LEGO to display the color palette with an axis indicating the value of the corresponding color on the right side of the picture.

Most options can be concatenated without spaces or commas, for example:

```
h->Draw("E1SAME");
```

The options are not case sensitive:

```
h->Draw("e1same");
```

The options `BOX`, `COL` and `COLZ`, use the color palette defined in the current style (see `TStyle::SetPalette`)

The options `CONT`, `SURF`, and `LEGO` have by default 20 equidistant contour levels, you can change the number of levels with `TH1::SetContour`.

You can also set the default drawing option with `TH1::SetOption`. To see the current option use `TH1::GetOption`.

For example:

```
  h->SetOption("lego");
  h->Draw();  // will use the lego option
  h->Draw("scat") // will use the scatter plot option
```

Statistics Display

By default, drawing a histogram includes drawing the statistics box. To eliminate the statistics box use: `TH1::SetStats(kFALSE)`.

If the statistics box is drawn, you can select the type of information displayed with `gStyle->SetOptStat(mode)`. The mode has up to seven digits that can be set to on (1) or off (0). Mode = `iourmen` (default = 0001111)

- `n` = 1 the name of histogram is printed
- `e` = 1 the number of entries printed
- `m` = 1 the mean value printed
- `r` = 1 the root mean square printed
- `u` = 1 the number of underflows printed
- `o` = 1 the number of overflows printed
- `i` = 1 the integral of bins printed

When trailing digits is left out, they are assumed 0. For example:

```
gStyle->SetOptStat(11);
```

This displays only the name of histogram and the number of entries.

When the option `"same"` is used, the statistic box is not redrawn; and hence the statistics from the previously drawn histogram will still show. With the option `"sames"`, you can rename a previous "`stats`" box and/or change its position with these lines:

```
root[ ]TPaveStats *st = (TPaveStats*)gPad->GetPrimitive("stats")
root[ ]st->SetName(newname)
root[ ]st->SetX1NDC(newx1); //new x start position
root[ ]st->SetX2NDC(newx2); //new x end position
root[ ]newhist->Draw("sames")
```

Setting Line, Fill, Marker, and Text Attributes

The histogram classes inherit from the attribute classes: `TAttLine`, `TAttFill`, `TAttMarker` and `TAttText`. See the description of these classes for the list of options.

Setting Tick Marks on the Axis

The `TPad::SetTicks` method specifies the type of tick marks on the axis. Assume `tx = gPad->GetTickx() and ty = gPad->GetTicky().`

- `tx` = 1; tick marks on top side are drawn (inside)
- `tx` = 2; tick marks and labels on top side are drawn
- `ty` = 1; tick marks on right side are drawn (inside)
- `ty` = 2; tick marks and labels on right side are drawn
- By default only the left Y axis and X bottom axis are drawn (`tx = ty = 0`)

Use `TPad::SetTicks(tx,ty)` to set these options. See also The `TAxis` methods to set specific axis attributes. In case multiple color filled histograms are drawn on the same pad, the fill area may hide the axis tick marks. One can force a redraw of the axis over all the histograms by calling:

```
gPad->RedrawAxis();
```

Giving Titles to the X, Y and Z Axis

Because the axis title is an attribute of the axis, you have to get the axis first and then call `TAxis::SetTitle`.

```
h->GetXaxis()->SetTitle("X axis title");
h->GetYaxis()->SetTitle("Y axis title");
```

The histogram title and the axis titles can be any `TLatex` string. The titles are part of the persistent histogram. For example if you wanted to write E with a subscript (T) you could use this:

```
h->GetXaxis()->SetTitle("E_{T}");
```

For a complete explanation of The Latex mathematical expressions see chapter "Graphics and Graphical User Interface".

The SCATter Plot Option

By default, 2D histograms are drawn as scatter plots. For each cell (i, j) a number of points proportional to the cell content is drawn. A maximum of 500 points per cell are drawn. If the maximum is above 500 contents are normalized to 500.

The ARRow Option

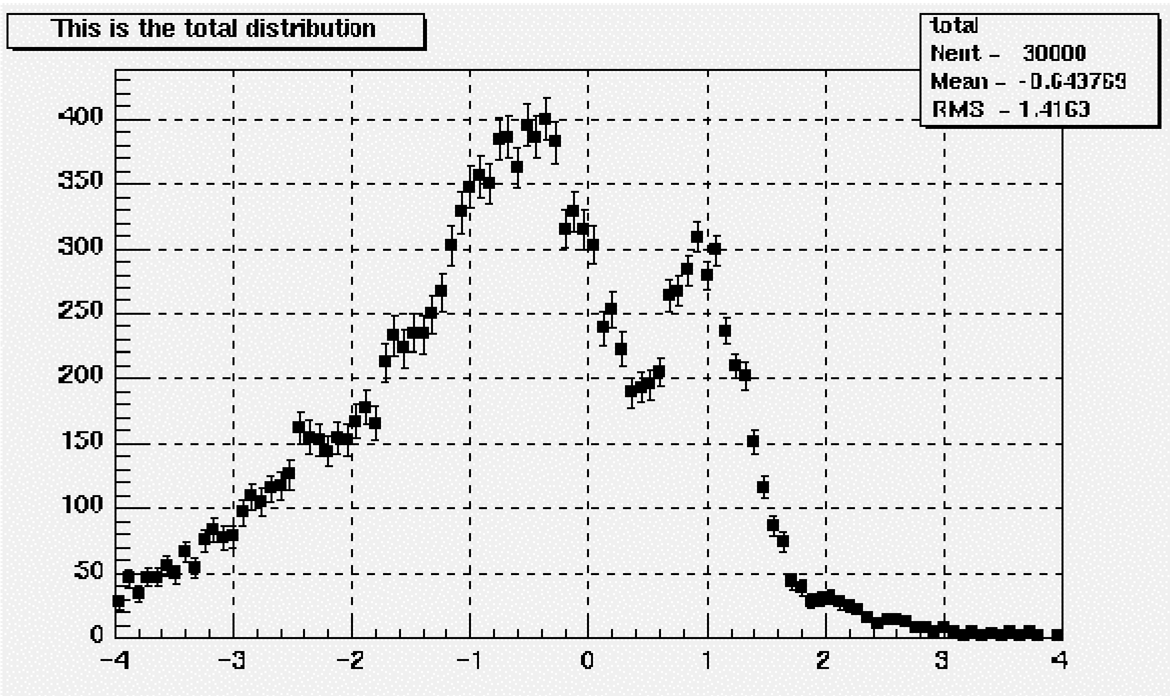
The ARR option shows the gradient between adjacent cells. For each cell (i,j) an arrow is drawn. The orientation of the arrow follows the cell gradient

The BOX Option

For each cell (i,j) a box is drawn with surface proportional to contents.

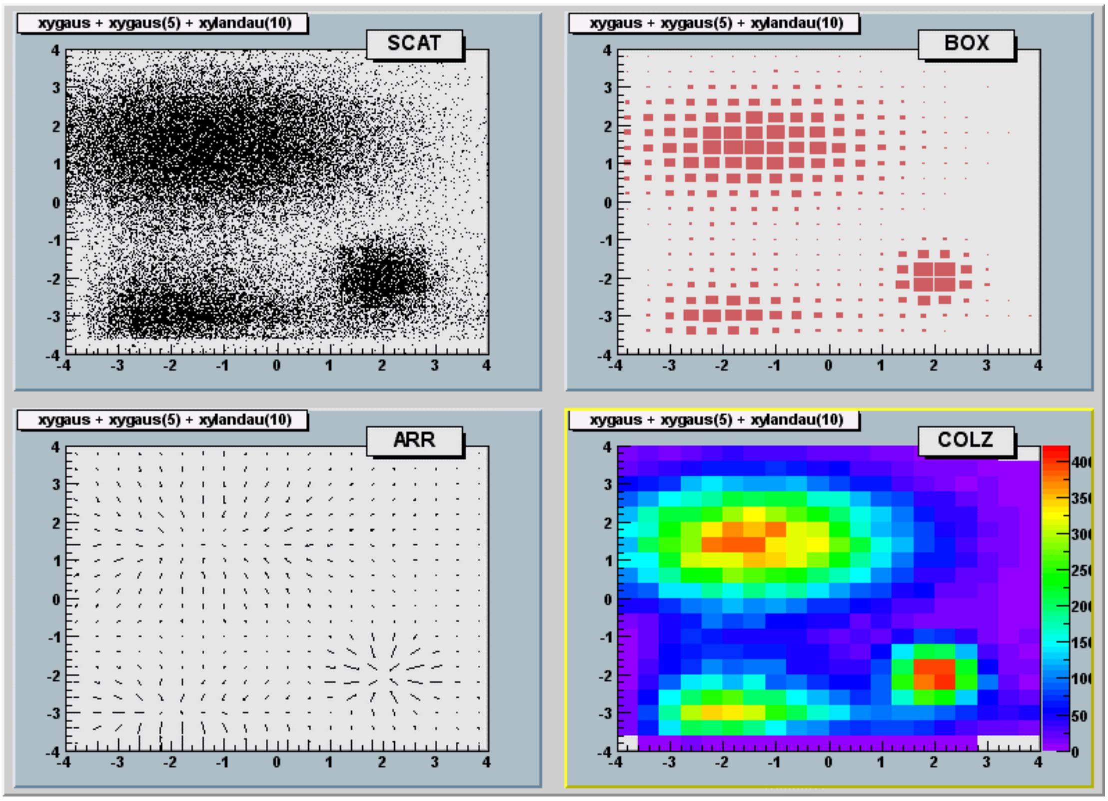
The ERRor Bars Options

- 'E' Default. Draw only the error bars, without markers
- 'E0' Draw also bins with 0 contents
- 'E1' Draw small lines at the end of the error bars
- 'E2' Draw error rectangles
- 'E3' Draw a fill area through the end points of the vertical error bars
- 'E4' Draw a smoothed filled area through the end points of the error bars



The COLor Option

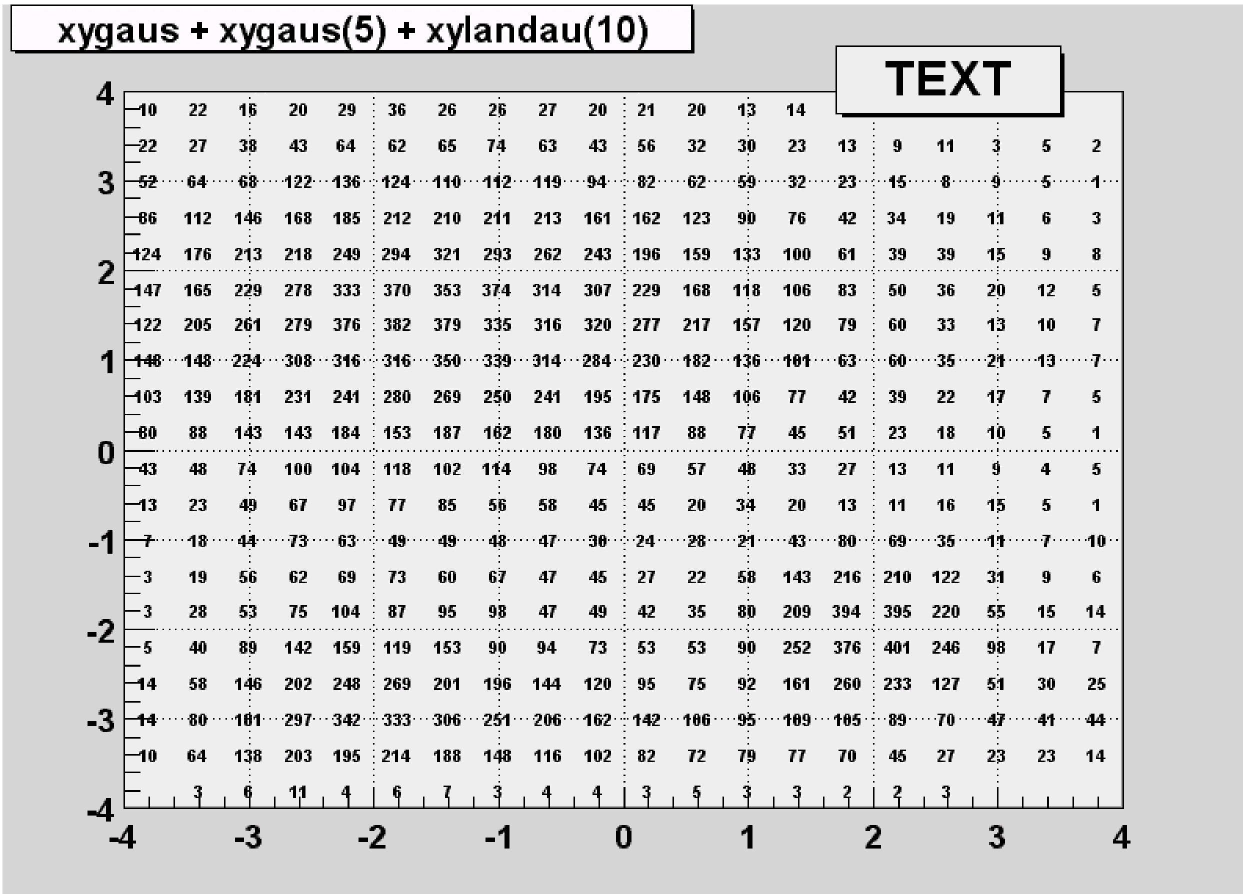
For each cell (i,j) a box is drawn with a color proportional to the cell content. The color table used is defined in the current style (`gStyle`). The color palette in `TStyle` can be modified with `TStyle::SetPalette`.



The TEXT Option

For each cell (i, j) the cell content is printed. The text attributes are:

- Text font = current `TStyle` font
- Text size = 0.02* pad-height * marker-size
- Text color = marker color



The CONTour Options

The following contour options are supported:

- "CONT": Draw a contour plot (same as CONT0)
- "CONT0": Draw a contour plot using surface colors to distinguish contours
- "CONT1": Draw a contour plot using line styles to distinguish contours
- "CONT2": Draw a contour plot using the same line style for all contours
- "CONT3": Draw a contour plot using fill area colors
- "CONT4": Draw a contour plot using surface colors (SURF option at theta = 0)

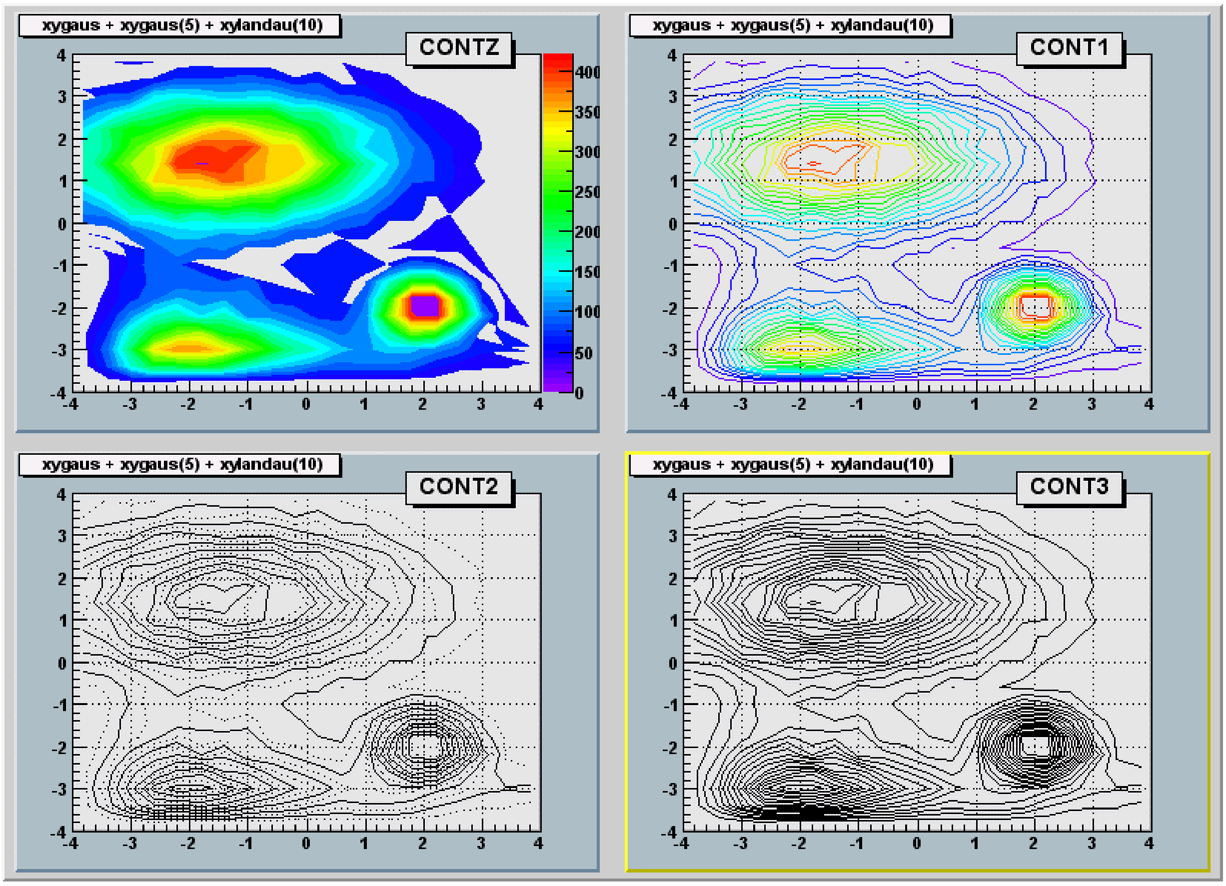
The default number of contour levels is 20 equidistant levels and can be changed with `TH1::SetContour`.

When option "LIST" is specified together with option "CONT", the points used to draw the contours are saved in the `TGraph` object and are accessible in the following way:

```
TObjArray *contours =
        gROOT->GetListOfSpecials()->FindObject("contours")
Int_t ncontours = contours->GetSize();
TList *list = (TList*)contours->At(i);
```

Where `"i"` is a contour number and list contains a list of `TGraph` objects. For one given contour, more than one disjoint poly-line may be generated. The number of `TGraphs` per contour is given by `list->GetSize()`. Here we show how to access the first graph in the list.

```
TGraph *gr1 = (TGraph*)list->First();
```



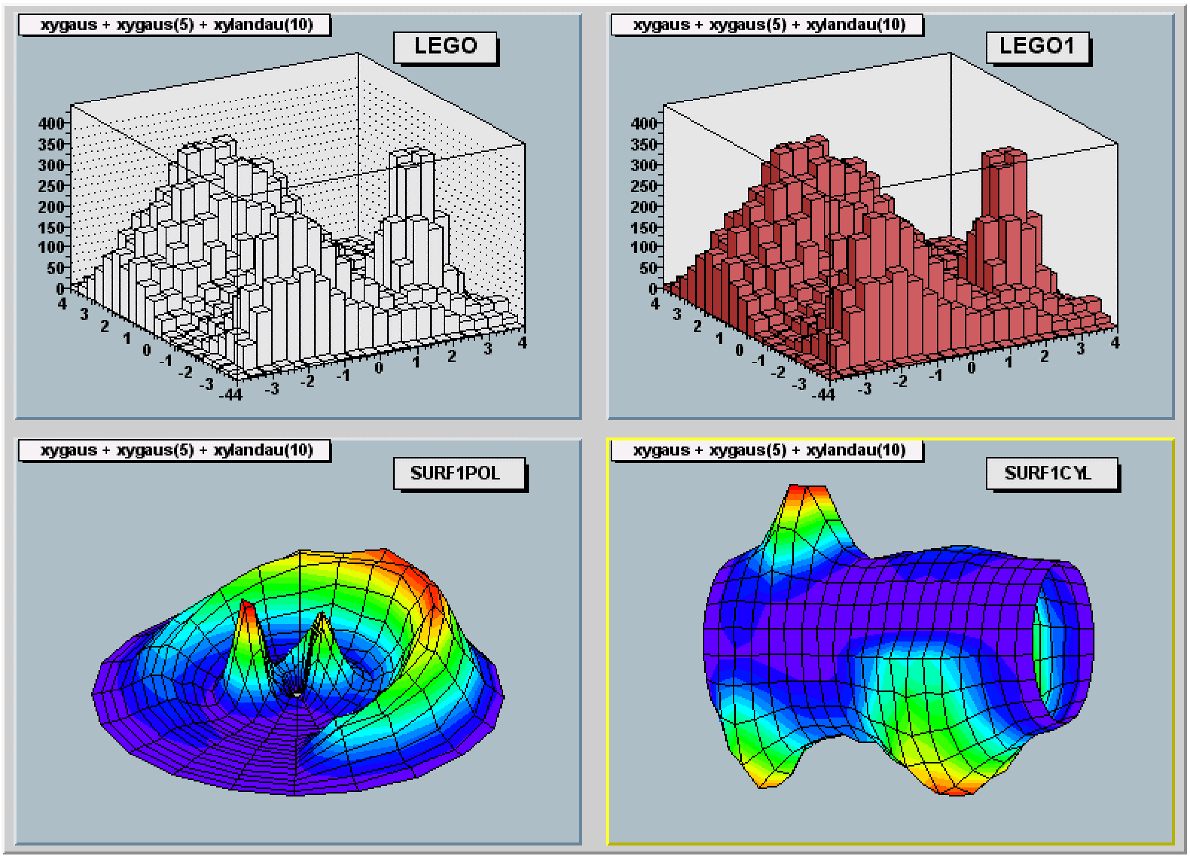
The LEGO Options

In a lego plot, the cell contents are drawn as 3-d boxes, with the height of the box proportional to the cell content. A lego plot can be represented in several coordinate systems; the default system is Cartesian coordinates. Other possible coordinate systems are `CYL, POL, SPH, and PSR`.

- "`LEGO`": Draw a lego plot with hidden line removal
- "`LEGO1`": Draw a lego plot with hidden surface removal
- "`LEGO2`": Draw a lego plot using colors to show the cell contents

See `TStyle::SetPalette` to change the color palette. We suggest you use palette 1 with the call

```
gStyle->SetColorPalette(1);
```



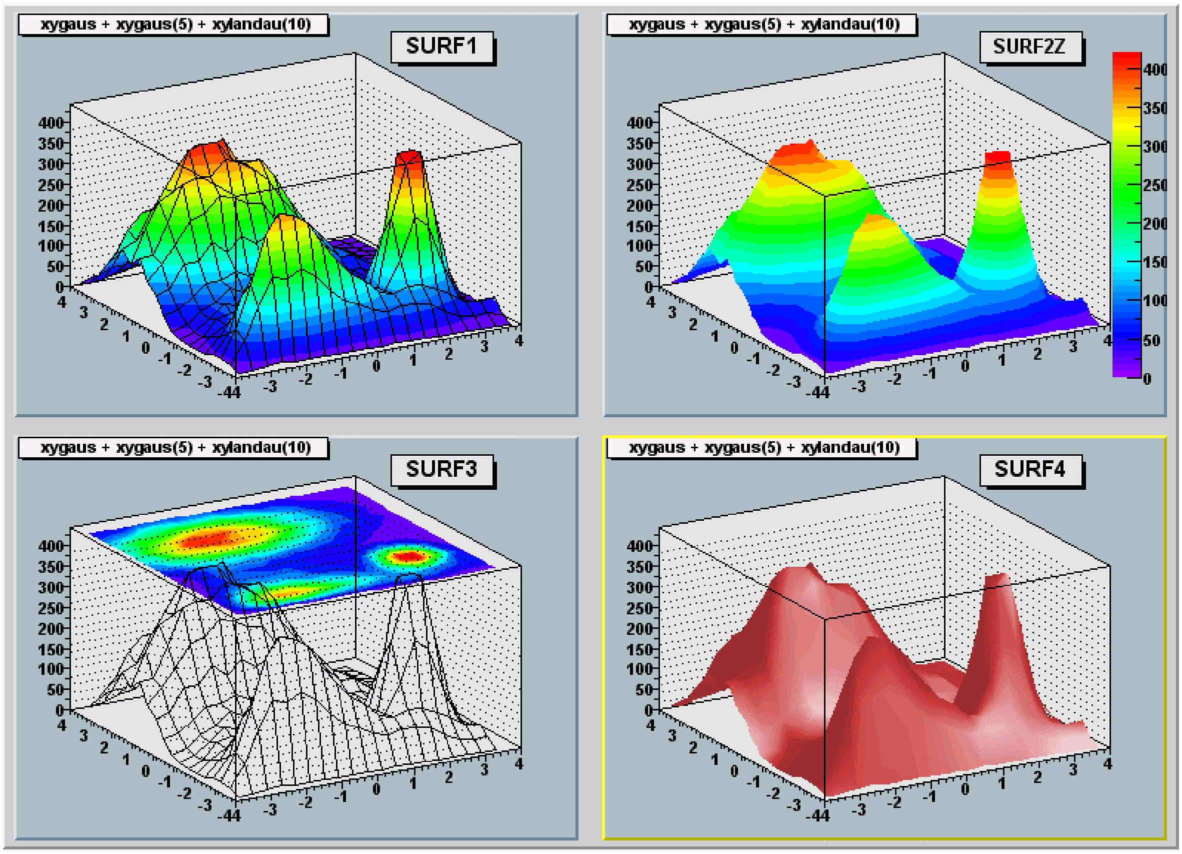
The SURFace Options

In a surface plot, cell contents are represented as a mesh. The height of the mesh is proportional to the cell content. A surface plot can be represented in several coordinate systems. The default is Cartesian coordinates, and the other possible systems are `CYL, POL, SPH, and PSR.`

- "SURF": Draw a surface plot with hidden line removal
- "SURF1": Draw a surface plot with hidden surface removal
- "SURF2": Draw a surface plot using colors to show the cell contents
- "SURF3": Same as SURF with a contour view on the top
- "SURF4": Draw a surface plot using Gouraud shading

The following picture uses SURF1. See `TStyle::SetPalette` to change the color palette. We suggest you use palette 1 with the call:

```
gStyle->SetColorPalette(1);
```



The Z Option: Display the Color Palette on the Pad

The "Z" option can be specified with the options : `BOX, COL, CONT, SURF, and LEGO` to display the color palette with an axis indicating the value of the corresponding color on the right side of the picture.

If there is not enough space on the right side, you can increase the size of the right margin by calling `TPad::SetRightMargin`.

The attributes used to display the palette axis values are taken from the Z axis of the object. For example, you can set the labels size on the palette axis with:

```
hist->GetZaxis()->SetLabelSize().
```

Setting the color palette

You can set the color palette with `TStyle::SetPalette`, e.g.

```
gStyle->SetPalette(ncolors,colors);
```

For example, the option `COL` draws a 2-D histogram with cells represented by a box filled with a color index, which is a function of the cell content. If the cell content is N, the color index used will be the color number in `colors[N]`. If the maximum cell content is greater than `ncolors`, all cell contents are scaled to `ncolors`.

If `ncolors <= 0`, a default palette (see below) of 50 colors is defined. This palette is recommended for pads, labels.

If `ncolors == 1` && `colors == 0`, a pretty palette with a violet to red spectrum is created. We recommend you use this palette when drawing lego plots, surfaces, or contours.

If `ncolors > 0` and `colors == 0`, the default palette is used with a maximum of `ncolors`.

The default palette defines:

- Index 0 to 9: shades of gray
- Index 10 to 19: shades of brown
- Index 20 to 29: shades of blue
- Index 30 to 39: shades of red
- Index 40 to 49: basic colors

The color numbers specified in the palette can be viewed by selecting the item "colors" in the "VIEW" menu of the canvas toolbar. The color's red, green, and blue values can be changed via `TColor::SetRGB`.

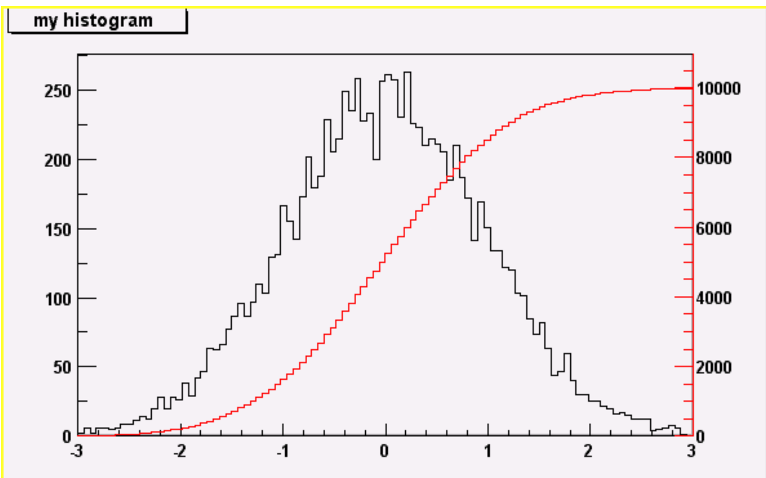
Drawing Options for 3-D Histograms

By default a 3-d scatter plot is drawn. If the "BOX" option is specified, a 3-D box with a volume proportional to the cell content is drawn.

Superimposing Histograms with Different Scales

The following script creates two histograms; the second histogram is the bins integral of the first one. It shows a procedure to draw the two histograms in the same pad and it draws the scale of the second histogram using a new vertical axis on the right side.

```
void twoscales() {
   TCanvas *c1 = new TCanvas("c1","hists with different
scales",600,400);

      //create, fill and draw h1
      gStyle->SetOptStat(kFALSE);
      TH1F *h1 = new TH1F("h1","my histogram",100,-3,3);
      Int_t i;
      for (i=0;i<10000;i++) h1->Fill(gRandom->Gaus(0,1));
      h1->Draw();
      c1->Update();

      //create hint1 filled with the bins integral of h1
     TH1F *hint1 = new TH1F("hint1","h1 bins integral",100,-3,3);
      Float_t sum = 0;
      for (i=1;i<=100;i++) {
         sum += h1->GetBinContent(i);
         hint1->SetBinContent(i,sum);
      }

      //scale hint1 to the pad coordinates
      Float_t rightmax = 1.1*hint1->GetMaximum();
      Float_t scale = gPad->GetUymax()/rightmax;
      hint1->SetLineColor(kRed);
      hint1->Scale(scale);
      hint1->Draw("same");

      //draw an axis on the right side
     TGaxis *axis = new TGaxis(gPad->GetUxmax(),gPad->GetUymin(),
           gPad->GetUxmax(),
           gPad->GetUymax(),0,rightmax,510,"+L");
      axis->SetLineColor(kRed);
      axis->SetTextColor(kRed);
      axis->Draw();
}
```



Making a Copy of an Histogram

Like for any other ROOT object derived from `TObject`, one can use the `Clone` method. This makes an identical copy of the original histogram including all associated errors and functions:

```
TH1F *hnew = (TH1F*)h->Clone();
hnew->SetName("hnew");
// renaming is recommended, because otherwise you will
// have 2 histograms with  the same name.
```

Normalizing Histograms

You can scale a histogram (TH1 *h) such that the bins integral is equal to the normalization parameter norm with:

```
  Double_t scale = norm/h->Integral();
  h->Scale(scale);
```

Saving/Reading Histograms to/from a file

The following statements create a ROOT file and store a histogram on the file. Because `TH1` derives from `TNamed`, the key identifier on the file is the histogram name:

```
TFile f("histos.root","new");
TH1F h1("hgaus","histo from a gaussian",100,-3,3);
h1.FillRandom("gaus",10000);
h1->Write();
```

To read this histogram in another ROOT session, do:

```
TFile f("histos.root");
TH1F *h = (TH1F*)f.Get("hgaus");
```

One can save all histograms in memory to the file by:

```
file->Write();
```

For a more detailed explanation, see chapter **Input/Output**

Miscellaneous Operations

- `TH1::KolmogorovTest()`: statistical test of compatibility in shape between two histograms.
- `TH1::Smooth()`: smoothes the bin contents of a 1-d histogram
- `TH1::Integral`: returns the integral of bin contents in a given bin range

- `TH1::GetMean(int axis)`:returns the mean value along axis
- `TH1::GetRMS(int axis)`:returns the Root Mean Square along axis
- `H1::GetEntries ()`: returns the number of entries
- `TH1::Reset()`: resets the bin contents and errors of a histogram

Profile Histograms

Profile histograms are in many cases an elegant replacement of two-dimensional histograms. The relationship of two quantities X and Y can be visualized by a two-dimensional histogram or a scatter-plot; its representation is not particularly satisfactory, except for sparse data. If Y is an unknown [but single-valued] function of X, it can be displayed by a profile histogram with much better precision than by a scatter-plot. Profile histograms display the mean value of Y and its RMS for each bin in X.

The following shows the contents [capital letters] and the values shown in the graphics [small letters] of the elements for bin j.

When you fill a profile histogram with `TProfile.Fill[x,y]`:
E[j] will contain for each bin j the sum of the y values for this bin
L[j] contains the number of entries in the bin j.
e[j] or s[j] will be the resulting error depending on the selected option described in Build Options below.

E[j] = sum Y
L[j] = number of entries in bin J

h[j] = H[j] / L[j]
s[j] = sqrt[E[j] / L[j] - h[j]**2]
e[j] = s[j] / sqrt[L[j]]

In the special case where s[j] is zero, when there is only one entry per bin, e[j] is computed from the average of the s[j] for all bins. This approximation is used to keep the bin during a fit operation.

The TProfile Constructor

The `TProfile` constructor takes up to six arguments. The first five parameters are similar to `TH1D::TH1D`.

```
TProfile(const char *name,const char *title,Int_t
nbins,Axis_t xlow,Axis_t xup,Option_t *option)
```

The first five parameters are similar to `TH1D::TH1D`. All values of `y` are accepted at filling time. To fill a profile histogram, you must use `TProfile::Fill` function.

Note that when filling the profile histogram the method `TProfile::Fill` checks if the variable `y` is between `fYmin` and `fYmax`. If a minimum or maximum value is set for the Y scale before filling, then all values below `ymin` or above `ymax` will be discarded. Setting the minimum or maximum value for the Y scale before filling has the same effect as calling the special `TProfile` constructor above where `ymin` and `ymax` are specified.

Build Options

The last parameter is the build option. If a bin has N data points all with the same value Y, which is the case when dealing with integers, the spread in Y for that bin is zero, and the uncertainty assigned is also zero, and the bin is ignored in making subsequent fits. If SQRT(Y) was the correct error in the case above, then SQRT(Y)/SQRT(N) would be the correct error here. In fact, any bin with non-zero number of entries N but with zero spread should have an uncertainty SQRT(Y)/SQRT(N).

Now, is SQRT(Y)/SQRT(N) really the correct uncertainty? That it is only in the case where the Y variable is some sort of counting statistics, following a Poisson distribution. This is the default case. However, Y can be any variable from an original NTUPLE, and does not necessarily follow a Poisson distribution.

The computation of errors is based on the parameter option:

Y = values of data points
N = number of data points

<u>' ' The default is blank, the Errors are:</u>

spread/SQRT(N)	for a non-zero spread
SQRT(Y)/SQRT(N)	for a spread of zero and some data points
0	for no data points

<u>'s' Errors are:</u>

spread	for a non-zero spread
SQRT(Y)	for a Spread of zero and some data points
0	for no data points

<u>'i' Errors are:</u>

spread/SQRT(N)	for a non-zero spread
1/SQRT(12*N)	for a Spread of zero and some data points
0	for no data points

<u>'G' Errors are:</u>

spread/SQRT(N)	for a non-zero spread
sigma/SQRT(N)	for a spread of zero and some data points
0	for no data points

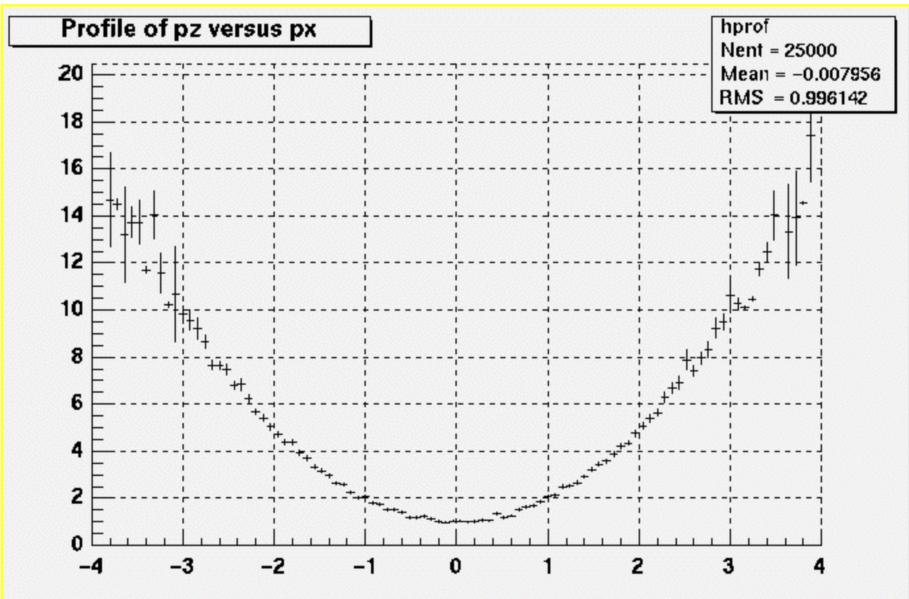
The third case (option 'i') is used for integer Y values with the uncertainty of +-0.5, assuming the probability that Y takes any value between Y-0.5 and Y+0.5 is uniform (the same argument for Y uniformly distributed between Y and Y+1). An example is an ADC measurement.

The 'G' option is useful, if all Y variables are distributed according to some known Gaussian of standard deviation Sigma. For example when all Y's are experimental quantities measured with the same instrument with precision Sigma.

Example of a TProfile

Here is a simple example of a profile histogram with its graphic output:

```
{
  // Create a canvas giving the coordinates and the size
  TCanvas *c1 = new TCanvas
     ("c1","Profile example",200,10,700,500);

  // Create a profile with the name, title, the number of
  // bins, the low and high limit of the x-axis and the low
  // and high limit of the y-axis. No option is given so
  // the default is used.
  hprof  = new TProfile
          ("hprof","Profile of pz versus px",100,-
4,4,0,20);

  // Fill the profile 25000 times with random numbers
  Float_t px, py, pz;
  for ( Int_t i=0; i<25000; i++) {

     // Use the random number generator to get two
     // numbers following a gaussian distribution
     // with mean=0 and sigma=1
     gRandom->Rannor(px,py);

     pz = px*px + py*py;
     hprof->Fill(px,pz,1);
  }

  hprof->Draw();
}
```



Drawing a Profile without Error Bars

To draw a profile histogram and not show the error bars use the "`HIST`" option in the `TProfile::Draw` method. This will draw the outline of the `TProfile`.

Create a Profile from a 2D Histogram

You can make a profile from a histogram using the methods `TH2::ProfileX` and `TH2::ProfileY`.

Create a Histogram from a Profile

To create a regular histogram from a profile histogram, use the method `TProfiel::ProjectionX`. This example instantiates a `TH1D` object by copying the `TH1D` piece of a `TProfile`.

```
TH1D *sum = myProfile.ProjectionX()
```

You can do the same with a 2D profile with the `TProfile2D::ProjectionXY method.`

Generating a Profile from a TTree

The `'prof'` and `'profs'` options in the `TTree::Draw` method (see the chapter on Trees) generate a profile histogram (`TProfile`), given a two dimensional expression in the tree.

2D Profiles

The class for a 2D Profile is called `TProfile2D`. It is in many cases an elegant replacement of a three-dimensional histogram. The relationship of three measured quantities X, Y and Z can be visualized by a three-dimensional histogram or scatter-plot; its representation is not particularly satisfactory, except for sparse data. If Z is an unknown (but single-valued) function of X,Y, it can be displayed with a `TProfile2D` with better precision than by a scatter-plot.

A TProfile2D displays the mean value of Z and its RMS for each cell in X,Y. The following shows the cumulated contents (capital letters) and the values displayed (small letters) of the elements for cell I, J.

When you fill a profile histogram with `TProfile2D.Fill[x,y,z]`:
E[i,j] will contain for each bin i,j the sum of the z values for this bin
L[i,j] contains the number of entries in the bin j.
e[j] or s[j] will be the resulting error depending on the selected option described in Build Options above.

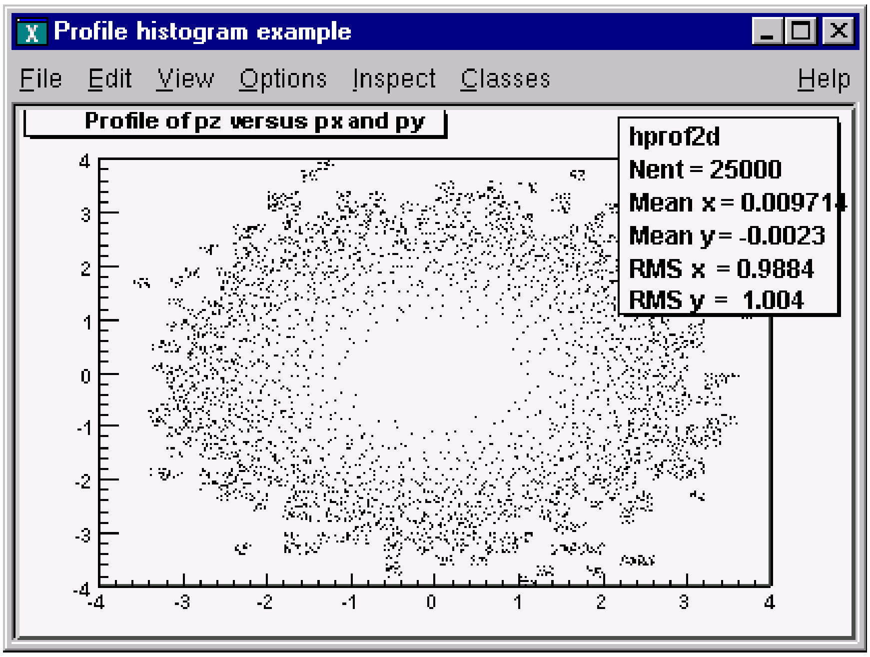
E[i,j] = sum z
L[i,j] = sum l
h[i,j] = H[i,j] / L[i,j]

s[i,j] = sqrt[E[i,j] / L[i,j]- h[i,j]**2]
e[i,j] = s[i,j] / sqrt[L[i,j]]

In the special case where s[`i,j`] is zero, when there is only one entry per cell, e[`i,j`] is computed from the average of the s[`i,j`] for all cells. This approximation is used to keep the cell during a fit operation.

Example of a TProfile2D histogram

```
{
  // Creating a Canvas and a TProfile2D
  TCanvas *c1 = new TCanvas
      ("c1","Profile histogram example",200,10,700,500);
  hprof2d  = new TProfile2D
      ("hprof2d","Profile of pz versus px and py"
      ,40,-4,4,40,-4,4,0,20);

  // Filling the TProfile2D with 25000 points
  Float_t px, py, pz;
  for ( Int_t i=0; i<25000; i++) {
     gRandom->Rannor(px,py);
     pz = px*px + py*py;
     hprof2d->Fill(px,py,pz,1);
  }
  hprof2d->Draw();
}
```



4 Graphs

A graph is a graphics object made of two arrays X and Y, holding the x, y coordinates of `n` points. There are several graph classes, they are: `TGraph`, `TGraphErrors`, `TGraphAsymmErrors`, and `TMultiGraph`.

TGraph

The `TGraph` class supports the general case with non equidistant points, and the special case with equidistant points.

Creating Graphs

Graphs are created with the constructor. Here is an example. First we define the arrays of coordinates and then create the graph. The coordinates can be arrays of doubles or floats.

```
Int_t n = 20;
Double_t x[n], y[n];

for (Int_t i=0;i<n;i++) {
  x[i] = i*0.1;
  y[i] = 10*sin(x[i]+0.2);
}

TGraph * gr1 = new TGraph (n, x, y);
```

An alternative constructor takes only the number of points (n). It is expected that the coordinates will be set later.

```
TGraph *gr2 = new TGraph(n);
```

Graph Draw Options

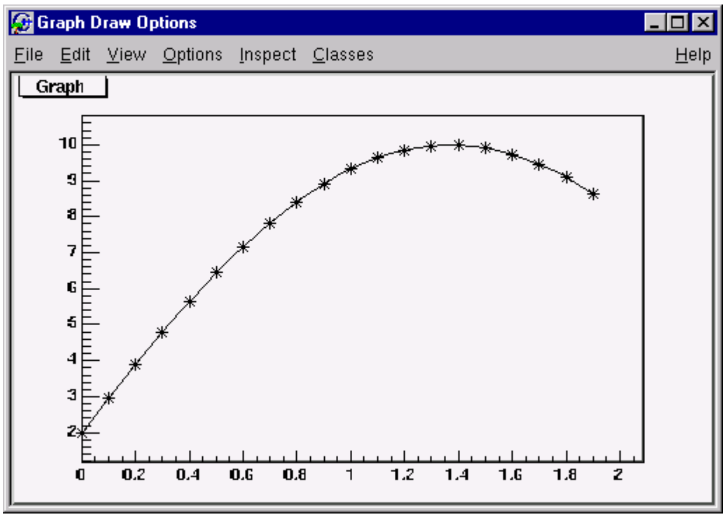
The various draw options for a graph are explained in `TGraph::PaintGraph`. They are:

- "L" A simple poly-line between every points is drawn
- "F" A fill area is drawn
- "A" Axis are drawn around the graph
- "C" A smooth curve is drawn
- " * " A star is plotted at each point
- "P" The current marker of the graph is plotted at each point
- "B" A bar chart is drawn at each point

The options are not case sensitive and they can be concatenated in most cases.

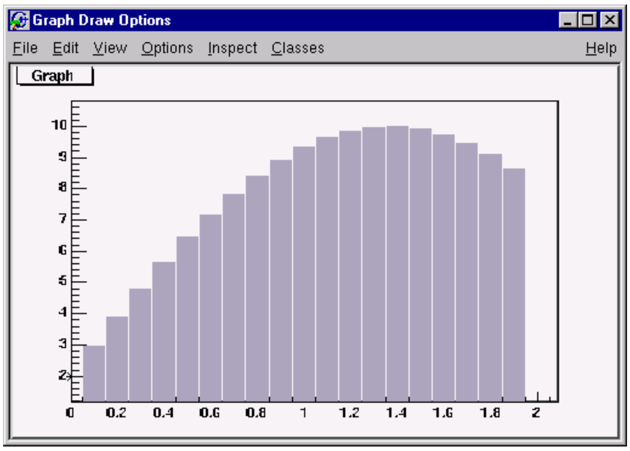
Let's look at some examples.

Continuous line, Axis and Stars (AC*)




```
{
  Int_t n = 20;
  Double_t x[n], y[n];

  for (Int_t i=0;i<n;i++) {
    x[i] = i*0.1;
    y[i] = 10*sin(x[i]+0.2);
  }

  // create graph
  TGraph *gr  = new TGraph(n,x,y);

  TCanvas *c1 = new TCanvas ("c1","Graph Draw Options",
200, 10, 600, 400);

  // draw the graph with axis,contineous line, and
  // put a * at each point
  gr->Draw("AC*");
}
```

Bar Graphs (AB)

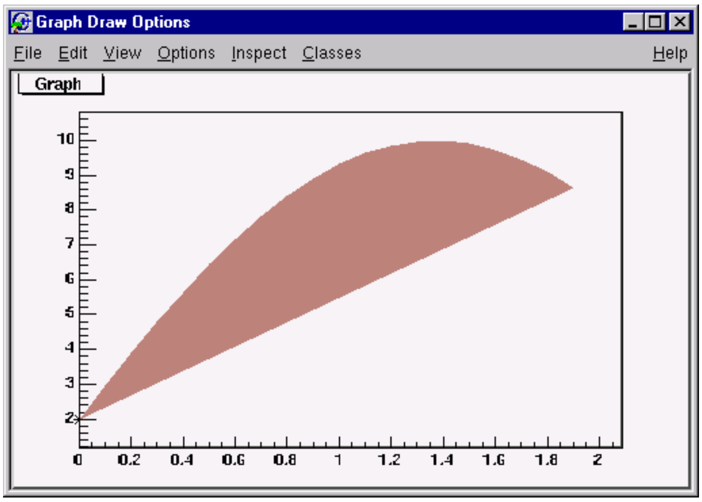



```
root [] 	TGraph *gr1 = new TGraph(n,x,y);
root [] 	gr1->SetFillColor(40);
root [] 	gr1->Draw("AB");
```

This code will only work if n, x, and y are defined. The previous example defines these.

You need to set the fill color, because by default the fill color is white and will not be visible on a white canvas. You also need to give it an axis, or the bar chart will not be displayed properly.

Filled Graphs (AF)



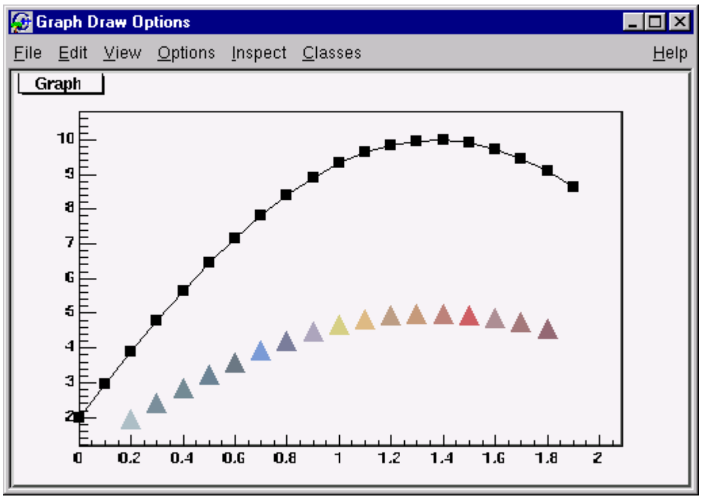

```
root [] TGraph *gr3 = new TGraph(n,x,y);
root [] gr3->SetFillColor(45);
root [] gr3->Draw("AF")
```

This code will only work if n, x, and y are defined. The first example defines these.

You need to set the fill color, because by default the fill color is white and will not be visible on a white canvas. You also need to give it an axis, or the bar chart will not be displayed properly.

Currently one can not specify the "CF" option.

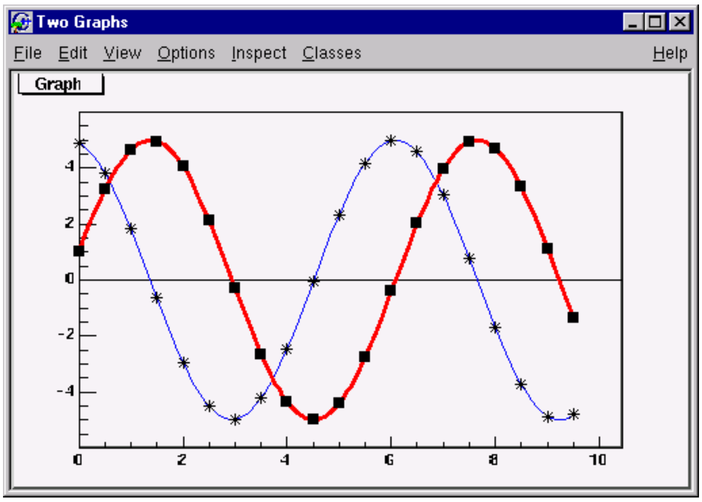
Marker Options




```
{
  Int_t n = 20;
  Double_t x[n], y[n];

  // build the arrays with the coordinate of points
  for (Int_t i=0;i<n;i++) {
    x[i] = i*0.1;
    y[i] = 10*sin(x[i]+0.2);
  }

  // create graphs
  TGraph *gr3  = new TGraph(n,x,y);

  TCanvas *c1 = new TCanvas ("c1","Graph Draw Options",
200,10, 600, 400);

  // draw the graph with the axis,contineous line, and put
  // a marker using the graph's marker style at each point
  gr3->SetMarkerStyle(21);
  c1->cd(4);
  gr3->Draw("APL");

  // get the points in the graph and put them into an array
  Double_t *nx = gr3->GetX();
  Double_t *ny = gr3->GetY();

  // create markers of different colors
  for (Int_t j=2;j<n-1;j++) {
      TMarker *m = new TMarker(nx[j], 0.5*ny[j],22);
            m->SetMarkerSize(2);
      m->SetMarkerColor(31+j);
      m->Draw();
   }
}
```

Superimposing two Graphs

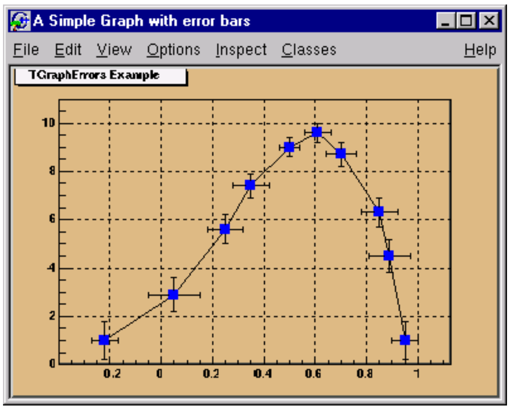
To super impose two graphs you need to draw the axis only once, and leave out the "A" in the draw options for the second graph. Here is an example:

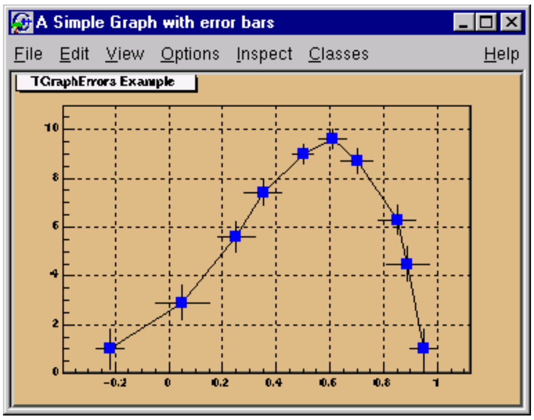



```
{
  gROOT->Reset();
  Int_t n = 20;
  Double_t x[n], y[n], x1[n], y1[n];

  // create the blue graph with a cos function
  for (Int_t i=0;i<n;i++) {
    x[i]  = i*0.5;
    y[i]  = 5*cos(x[i]+0.2);
    x1[i] = i*0.5;
    y1[i] = 5*sin(x[i]+0.2);
  }

  TGraph *gr1 = new TGraph(n,x,y);
  TGraph *gr2  = new TGraph(n,x1,y1);

  TCanvas *c1 = new TCanvas ("c1","Two Graphs" , 200,
     10, 600, 400);

  // draw the graph with axis,contineous line, and
  // put a * at each point
  gr1->SetLineColor(4);
  gr1->Draw("AC*");

  // superimpose the second graph by leaving out
  // the axis option "A"
  gr2->SetLineWidth(3);
  gr2->SetMarkerStyle(21);
  gr2->SetLineColor(2);
  gr2->Draw("CP");
}
```

TGraphErrors

A `TGraphErrors` is a `TGraph` with error bars. The various format options to draw a `TGraphErrors` are the same for `TGraph`. In addition, it can be drawn with the "Z" option to leave off the small lines at the end of the error bars.



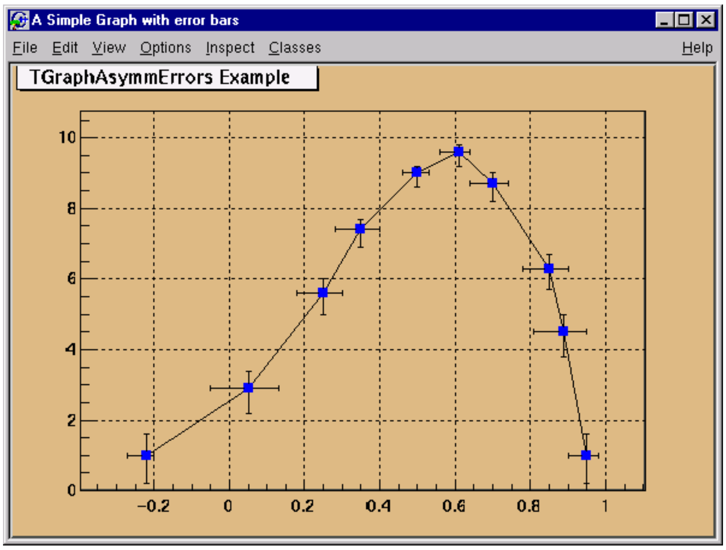


The constructor has four arrays as parameters. X and Y as in `TGraph` and X-errors and Y-errors the size of the errors in the x and y direction.

This example is in `$ROOTSYS/tutorials/gerrors.C`.

```
{
  gROOT->Reset();

  c1 = new TCanvas("c1","A Simple Graph with error
bars",200,10,700,500);

   c1->SetFillColor(42);
   c1->SetGrid();
   c1->GetFrame()->SetFillColor(21);
   c1->GetFrame()->SetBorderSize(12);

  // create the coordinate arrays
   Int_t n = 10;
   Float_t x[n]  = {-.22,.05,.25,.35,.5,.61,.7,.85,.89,.95};
   Float_t y[n]  = {1,2.9,5.6,7.4,9,9.6,8.7,6.3,4.5,1};

  // create the error arrays
   Float_t ex[n] = {.05,.1,.07,.07,.04,.05,.06,.07,.08,.05};
   Float_t ey[n] = {.8,.7,.6,.5,.4,.4,.5,.6,.7,.8};

  // create the TGraphErrors and draw it
   gr = new TGraphErrors(n,x,y,ex,ey);
   gr->SetTitle("TGraphErrors Example");
   gr->SetMarkerColor(4);
   gr->SetMarkerStyle(21);
   gr->Draw("ALP");

   c1->Update();
}
```

TGraphAsymmErrors



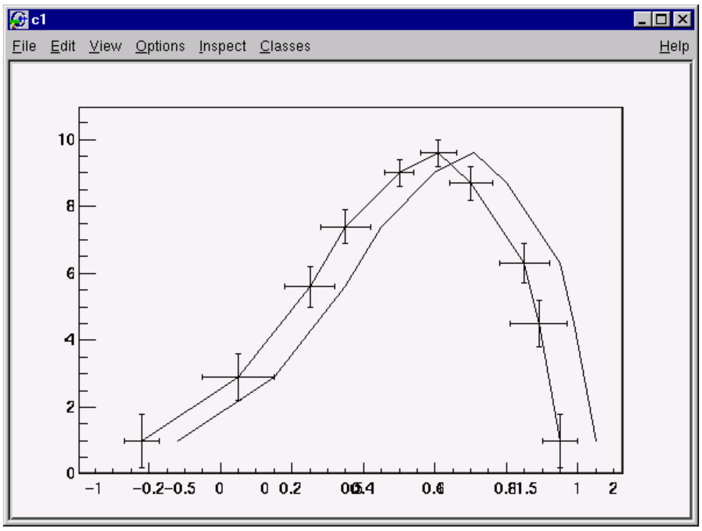
A `TGraphAsymmErrors` is a `TGraph` with asymmetric error bars. The various format options to draw a `TGraphAsymmErrors` are as for `TGraph`.

The constructor has six arrays as parameters. X and Y as `TGraph` and low X-errors and high X-errors, low Y-errors and high Y-errors. The low value is the length of the error bar to the left and down, the high value is the length of the error bar to the right and up.

```
{
   gROOT->Reset();
   c1 = new TCanvas ("c1","A Simple Graph with error bars",
                       200,10,700,500);
   c1->SetFillColor(42);
   c1->SetGrid();
   c1->GetFrame()->SetFillColor(21);
   c1->GetFrame()->SetBorderSize(12);

   // create the arrays for the points
   Int_t n = 10;
   Double_t x[n]  = {-.22,.05,.25,.35,.5, .61,.7,.85,.89,.95};
   Double_t y[n]  = {1,2.9,5.6,7.4,9,9.6,8.7,6.3,4.5,1};

   // create the arrays with high and low errors
   Double_t exl[n] = {.05,.1,.07,.07,.04,.05,.06,.07,.08,.05};
   Double_t eyl[n] = {.8,.7,.6,.5,.4,.4,.5,.6,.7,.8};
   Double_t exh[n] = {.02,.08,.05,.05,.03,.03,.04,.05,.06,.03};
   Double_t eyh[n] = {.6,.5,.4,.3,.2,.2,.3,.4,.5,.6};

   // create TGraphAsymmErrors with the arrays
   gr = new TGraphAsymmErrors(n,x,y,exl,exh,eyl,eyh);
   gr->SetTitle("TGraphAsymmErrors Example");
   gr->SetMarkerColor(4);
   gr->SetMarkerStyle(21);
   gr->Draw("ALP");
}
```

TMultiGraph

A `TMultiGraph` is a collection of `TGraph` (or derived) objects. Use `TMultiGraph::Add` to add a new graph to the list. The `TMultiGraph` owns the objects in the list. The drawing options are the same as for `TGraph`.




```
{
   // create the points
   Int_t n = 10;
   Double_t x[n]  = {-.22,.05,.25,.35,.5,.61,.7,.85,.89,.95};
   Double_t y[n]  = {1,2.9,5.6,7.4,9,9.6,8.7,6.3,4.5,1};

    Double_t x2[n]  = {-.12,.15,.35,.45,.6,.71,.8,.95,.99,1.05};
    Double_t y2[n]  = {1,2.9,5.6,7.4,9,9.6,8.7,6.3,4.5,1};

   // create the width of errors in x and y direction
   Double_t ex[n] = {.05,.1,.07,.07,.04,.05,.06,.07,.08,.05};
   Double_t ey[n] = {.8,.7,.6,.5,.4,.4,.5,.6,.7,.8};

   // create two graphs
   TGraph *gr1 = new TGraph(n,x2,y2);
   TGraphErrors *gr2 = new TGraphErrors(n,x,y,ex,ey);

   // create a multigraph and draw it
   TMultiGraph  *mg  = new TMultiGraph();
   mg->Add(gr1);
   mg->Add(gr2);
   mg->Draw("ALP");
}
```

Fitting a Graph

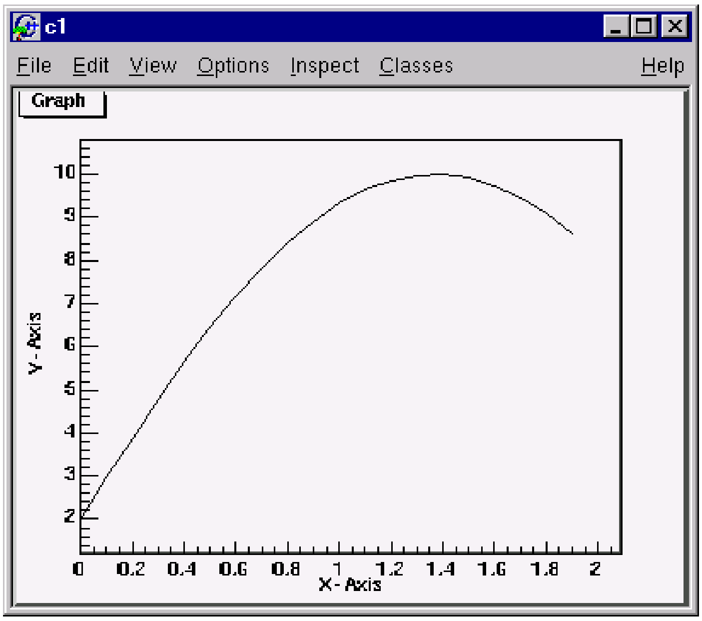
The `Fit` method of the graph works the same as the TH1::Fit (see Fitting Histograms).

Setting the Graph's Axis Title

To give the axis of a graph a title you need to draw the graph first, only then does it actually have an axis object. Once drawn, you set the title by getting the axis and calling the `TAxis::SetTitle` method, and if you want to center it you can call the `TAxis::CenterTitle` method.

Assuming that n, x, and y are defined, this code sets the titles of the x and y axes.

```
root [] gr5 = new TGraph(n,x,y);
root [] gr5->Draw()
<TCanvas::MakeDefCanvas>: created default TCanvas with name c1
root [] gr5->Draw("ALP")
root [] gr5->GetXaxis()->SetTitle("X-Axis")
root [] gr5->GetYaxis()->SetTitle("Y-Axis")
root [] gr5->GetXaxis()->CenterTitle()
root [] gr5->GetYaxis()->CenterTitle()
root [] gr5->Draw("ALP")
```



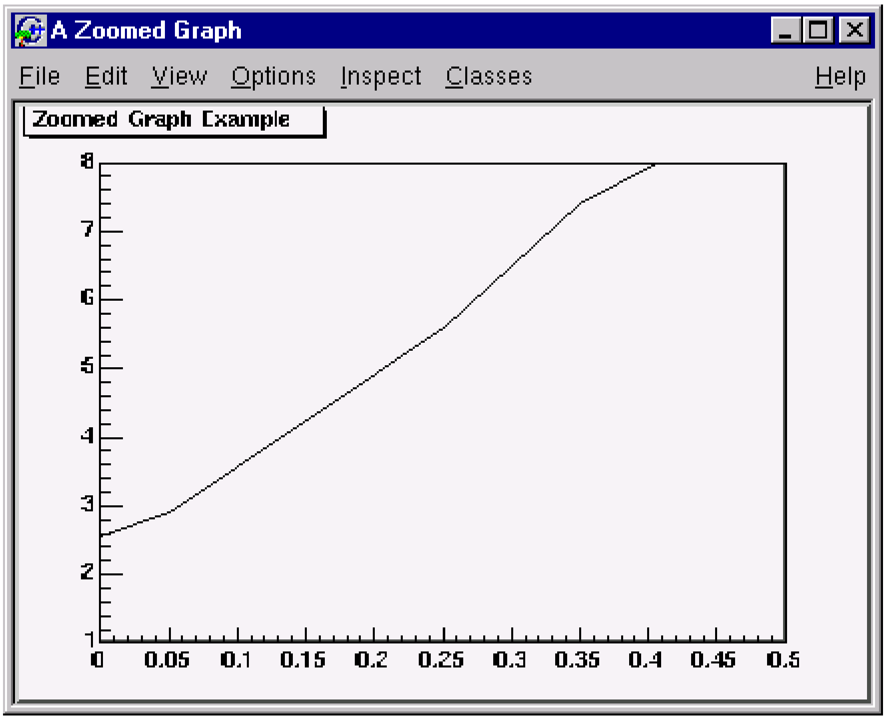
For more graph examples see: these scripts in the `$ROOTSYS/tutorials` directory `graph.C`, `gerrors.C`, `zdemo.C`, and `gerrors2.C`.

Zooming a Graph

To zoom a graph you can create a histogram with the desired axis range first. Draw the empty histogram and then draw the graph using the existing axis from the histogram.

The example below is the same graph as above with a zoom in the x and y direction.

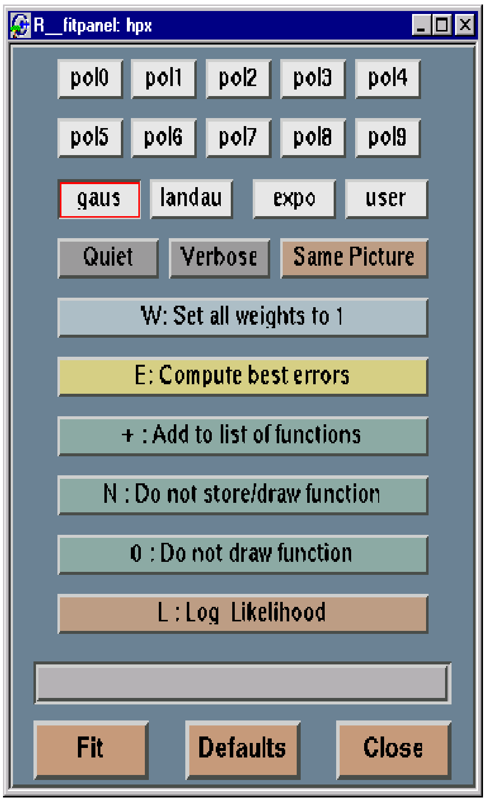
```
{
  gROOT->Reset();
  c1 = new TCanvas("c1","A Zoomed Graph",200,10,700,500);

  // create a histogram for the axis range
  hpx = new TH2F
        ("hpx","Zoomed Graph Example",10, 0,0.5,10,1.0,8.0);
  // no statistics
  hpx->SetStats(kFALSE);
  hpx->Draw();

  // create a graph
  Int_t n = 10;
  Double_t x[n] = {-.22,.05,.25,.35,.5,.61,.7,.85,.89,.95};
  Double_t y[n] = {1,2.9,5.6,7.4,9,9.6,8.7,6.3,4.5,1};
  gr = new TGraph(n,x,y);
  gr->SetMarkerColor(4);
  gr->SetMarkerStyle(20);
  // and draw it without an axis
  gr->Draw("LP");
}
```



5 Fitting Histograms

To fit a histogram you can use the Fit Panel on a visible histogram using the GUI, or you can use the `TH1::Fit` method. The Fit Panel, which is limited, is best for prototyping. The histogram needs to be drawn in a pad before the Fit Panel is available. The `TH1::Fit` method is more powerful and used in scripts and programs.

The Fit Panel



To display the Fit Panel right click on a histogram to bring up the context menu, then select the menu option: FitPanel.

The first sets of buttons are the predefined functions of ROOT that can be used to fit the histogram. You have a choice of several polynomials, a gaussian, a landau, and an exponential function. You can also define a function and call it "user". It will be linked to the user button on this panel.

You have the option to specify Quiet or Verbose. This is the amount of feedback printed on the root command line on the result of the fit.

When a fit is executed the image of the function is drawn on the current pad. By default the image of the histogram is replaced with the image of the function. Select Same Picture to see the function drawn and the histogram on the same picture.

Select W: Set all weights to 1, to set all errors to 1.

Select E: Compute best errors to use the Minos technique to compute best errors.

When fitting a histogram, the function is attached to the histogram's list of functions. By default the previously fitted function is deleted and replaced with the most recent one, so the list only contains one function. You can select + : Add to list of functions to add the newly fitted function to the existing list of functions for the histogram. Note that the fitted functions are saved with the histogram when it is written to a ROOT file.

By default, the function is drawn on the pad displaying the histogram. Select N: Do not store/draw function to avoid adding the function to the histogram and to avoid drawing it.

Select 0: Do not draw function to avoid drawing the result of the fit.

Select L: Log Likelihood to use loglikelihood method (default is chisquare method).

The slider at the bottom of the panel allows you to set a range for the fit. Drag the edges of the slider towards the center to narrow the range. Draw the entire range to change the beginning and end.

To returns to the original setting, you need press Defaults.

To apply the fit, press the Fit button.

The Fit Method

To fit a histogram programmatically, you can use the `TH1::Fit` method. Here is the signature of `TH1::Fit` and an explanation of the parameters:

```
void Fit(const char *fname , Option_t *option , Option_t
*goption, Axis_t xxmin,  Axis_t  xxmax)
```

`*fname:` The name of the fitted function (the model) is passed as the first parameter. This name may be one of the of ROOT's pre-defined function names or a user-defined function.

The following functions are predefined, and can be used with the TH1::Fit method.

- **`gaus`**: A gaussian function with 3 parameters: `f(x) = p0*exp(-0.5*((x-p1)/p2)^2))`
- **`expo`**: An exponential with 2 parameters: `f(x) = exp(p0+p1*x).`
- **`polN`**: A polynomial of degree N: f(x) = p0 + p1*x + p2*x^2 +...
- **`landau`**: A landau function with mean and sigma. This function has been adapted from the CERNLIB routine G110 `denlan`.

`*option:` The second parameter is the fitting option. Here is the list of fitting options:

- "W" Set all errors to 1
- "I" Use integral of function in bin instead of value at bin center
- "L" Use loglikelihood method (default is chisquare method)
- "U" Use a user specified fitting algorithm
- "Q" Quiet mode (minimum printing)
- "V" Verbose mode (default is between Q and V)
- "E" Perform better errors estimation using Minos technique
- "M" Improve fit results
- "R" Use the range specified in the function range
- "N" Do not store the graphics function, do not draw
- "0" Do not plot the result of the fit. By default the fitted function is drawn unless the option "N" above is specified.
- "+" Add this new fitted function to the list of fitted functions (by default, the previous function is deleted and only the last one is kept)
- "B" Disable the automatic computation of the initial parameter values for the standard functions like `poln`, `expo`, and `gaus`.

`*goption:` The third parameter is the graphics option (`goption`), it is the same as in the `TH1::Draw` (see Draw Options above) .

xxmin, xxmax: The fourth and fifth parameters specify the range over which to apply the fit

By default, the fitting function object is added to the histogram and is drawn in the current pad.

Fit with a Predefined Function

To fit a histogram with a predefined function, simply pass the name of the function in the first parameter of TH1::Fit. For example, this line fits histogram object hist with a gaussian.

```
root[] hist.Fit("gaus");
```

For pre-defined functions, there is no need to set initial values for the parameters, it is done automatically.

Fit with a User- Defined Function

You can create a TF1 object and use it in the call the TH1::Fit. The parameter in to the Fit method is the NAME of the TF1 object.

There are three ways to create a TF1.

1. Using C++ like expression using x with a fixed set of operators and functions defined in TFormula.
2. Same as #1, with parameters
3. Using a function that you have defined

Creating a TF1 with a Formula

Let's look at the first case. Here we call the TF1 constructor by giving it the formula: sin(x)/x.

```
root[] TF1  *f1 = new TF1("f1", "sin(x)/x", 0,10)
```

You can also use a TF1 object in the constructor of another TF1.

```
root[] TF1  *f2 = new TF1("f2", "f1 * 2", 0,10)
```

Creating a TF1 with Parameters

The second way to construct a TF1 is to add parameters to the expression. For example, this TF1 has 2 parameters:

```
root[] TF1 *f1 = new TF1("f1","[0]*x*sin([1]*x)",-3,3);
```

The parameter index is enclosed in square brackets. To set the initial parameters explicitly you can use the SetParameter method.

```
root[] f1->SetParameter(0,10);
```

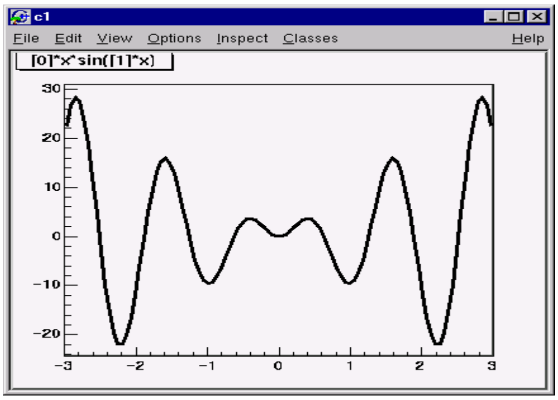
This sets parameter 0 to 10. You can also use SetParameters to set multiple parameters at once.

```
root[] f1->SetParameters(10,5);
```

This sets parameter 0 to 10 and parameter 1 to 5.

We can now draw the TF1:

```
root[] f1->Draw()
```



Creating a TF1 with a User Function

The third way to build a TF1 is to define a function yourself and then give its name to the constructor. A function for a TF1 constructor needs to have this exact signature:

```
Double_t fitf(Double_t *x, Double_t *par)
```

The two parameters are:

- Double_t *x: a pointer to the dimension array. Each element contains a dimension. For a 1D histogram only x[0] is used, for a 2D histogram x[0] and x[1] is used, and for a 3D histogram x[0], x[1], and x[2] are used. For histograms, only 3 dimensions apply, but this method is also used to fit other objects, for example a ntuple could have 10 dimensions.
- Double_t *par: a pointer to the parameters array. This array contains the current values of parameters when it is called by the fitting function.

The following script $ROOTSYS/tutorials/myfit.C illustrates how to fit a 1D histogram with a user-defined function. First we declare the function.

```
// define a function with 3 parameters
Double_t fitf(Double_t *x, Double_t *par)
{
  Double_t arg = 0;
  if (par[2]) arg = (x[0] - par[1])/par[2];
  Double_t fitval = par[0]*TMath::Exp(-0.5*arg*arg);
  return fitval;
}
```

Now we use the function:

```
// this function used fitf to fit a histogram
void fitexample()
{
  // open a file and get a histogram
  TFile *f = new TFile("hsimple.root");
  TF1 *hpx = (TF1*)f->Get("hpx");

  // create a TF1 object using the function defined above.
  // The last 3 specifies the number of parameters
  // for the function.
  TF1 *func = new TF1 "fit",fitf,-3,3,3);

  // set the parameters to the mean and RMS of the histogram
  func->SetParameters(500,hpx->GetMean(),hpx->GetRMS());
  // give the parameters meaningful names
  func->SetParNames ("Constant","Mean_value","Sigma");

  // call TH1::Fit with the name of the TF1 object
  hpx->Fit ("fit");
}
```

Fitting Sub Ranges

By default,`TH1::Fit` will fit the function on the defined histogram range. You can specify the option "**R**" in the second parameter of `TH1::Fit` to restrict the fit to the range specified in the `TF1` constructor. In this example, the fit will be limited to –3 to 3, the range specified in the `TF1` constructor.

```
root[] TF1 *f1 = new TF1("f1","[0]*x*sin([1]*x)",-3,3);
root[] hist->Fit("f1", "R");
```

You can also specify a range in the call to `TH1::Fit`:

```
root[] hist->Fit("f1","","",-2,2)
```

For more complete examples, see `$ROOTSYS/tutorials/myfit.C` and `$ROOTSYS/tutorials/multifit.C`.

Adding Functions to The List

The example `$ROOTSYS/tutorials/multifit.C` also illustrates how to fit several functions on the same histogram. By default a Fit command deletes the previously fitted function in the histogram object. You can specify the option "+" in the second parameter to add the newly fitted function to the existing list of functions for the histogram.

```
root[] hist->Fit("f1","+","",-2,2)
```

Note that the fitted function(s) are saved with the histogram when it is written to a ROOT file.

Combining Functions

You can combine functions to fit a histogram with their sum. Here is an example, the code is in `$ROOTSYS/tutorials/FitDemo.C`. We have a function that is the combination of a background and lorenzian peak. Each function contributes 3 parameters.

$$y(E) = a_1 + a_2E + a_3E^2 \quad + \quad A_P \; (G / 2 p)/((E-m)^2 + (G/2)^2)$$

background	lorenzianPeak
par[0] = a_1	**par[0] = A_P**
par[1] = a_2	**par[1] = G**
par[2] = a_3	**par[2] = m**

The combination function (`fitFunction`) has six parameters:

fitFunction = background (x, par) + lorenzianPeak (x, &par[3])

par[0] = a_1

par[1] = a_2

par[2] = a_3

par[3] = A_p

par[4] = G

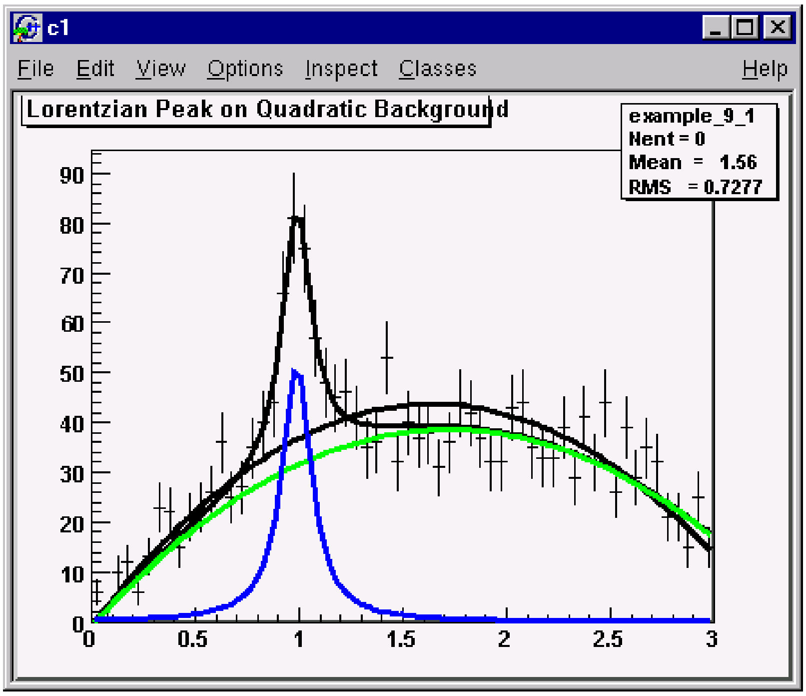
par[5] = m

This script creates a histogram and fits the combination of the two functions. First we define the two functions and the combination function:

```
// Quadratic background function
Double_t background(Double_t *x, Double_t *par) {
   return par[0] + par[1]*x[0] + par[2]*x[0]*x[0];
}


// Lorenzian Peak function
Double_t lorentzianPeak(Double_t *x, Double_t *par) {
  return (0.5*par[0]*par[1]/TMath::Pi()) /
          TMath::Max( 1.e-10,
                     (x[0]-par[2])*(x[0]-par[2]) +
.25*par[1]*par[1]
                    );
}

// Sum of background and peak function
Double_t fitFunction(Double_t *x, Double_t *par) {
  return background(x,par) + lorentzianPeak(x,&par[3]);
}

// … continued on the next page
```

```
void FittingDemo() {
// Bevington Exercise by Peter Malzacher,
// modified by Rene Brun

   const int nBins = 60;

   Stat_t data[nBins] = { 6, 1,10,12, 6,13,23,22,15,21,
                         23,26,36,25,27,35,40,44,66,81,
                         75,57,48,45,46,41,35,36,53,32,
                         40,37,38,31,36,44,42,37,32,32,
                         43,44,35,33,33,39,29,41,32,44,
                         26,39,29,35,32,21,21,15,25,15};
   TH1F *histo = new TH1F("example_9_1",
     "Lorentzian Peak on Quadratic Background",60,0,3);

   for(int i=0; i < nBins;  i++) {
       // we use these methods to explicitly set the content
       // and error instead of using the fill method.
      histo->SetBinContent(i+1,data[i]);
      histo->SetBinError(i+1,TMath::Sqrt(data[i]));
   }

   // create a TF1 with the range from 0 to 3
   // and 6 parameters
   TF1 *fitFcn = new TF1("fitFcn",fitFunction,0,3,6);

   // first try without starting values for the parameters
   // This defaults to 1 for each param.
   histo->Fit("fitFcn");
   // this results in an ok fit for the polynomial function
   // however the non-linear part (lorenzian) does not
   // respond well.


   // second try: set start values for some parameters
   fitFcn->SetParameter(4,0.2); // width
   fitFcn->SetParameter(5,1);   // peak

   histo->Fit("fitFcn","V+");

   // improve the picture:
   TF1 *backFcn = new TF1("backFcn",background,0,3,3);
   backFcn->SetLineColor(3);
   TF1 *signalFcn = new TF1("signalFcn",lorentzianPeak,0,3,3);
   signalFcn->SetLineColor(4);
   Double_t par[6];

   // writes the fit results into the par array
   fitFcn->GetParameters(par);

   backFcn->SetParameters(par);
   backFcn->Draw("same");

   signalFcn->SetParameters(&par[3]);
   signalFcn->Draw("same");
}
```

This is the result:



For another example see:
http://root.cern.ch/root/html/examples/backsig.C.html

Associated Function

One or more objects (typically a `TF1*`) can be added to the list of functions (`fFunctions`) associated to each histogram. A call to `TH1::Fit` adds the fitted function to this list. Given a histogram `h`, one can retrieve the associated function with:

```
TF1 *myfunc = h->GetFunction("myfunc");
```

Access to the Fit Parameters and Results

If the histogram (or graph) is made persistent, the list of associated functions is also persistent. Retrieve a pointer to the function with the `TH1::GetFunction()` method. Then you can retrieve the fit parameters from the function (`TF1`) with calls such as:

```
    root[] TF1 *fit = hist->GetFunction(function_name);
    root[] Double_t chi2 = fit->GetChisquare();
// value of the first parameter
    root[] Double_t p1 = fit->GetParameter(0);
// errro of the first parameter
    root[] Double_t e1 = fit->GetParError(0);
```

Fitting Between Parameter Bounds

To set bounds for one parameter, use `TF1::SetParLimits`:

```
root[] func->SetParLimits(0, -1, 1);
```

Where `func` is the pointer to the function to be fitted. If you only have the function name, you can get the pointer to this function with:

```
root[] gROOT->GetFunction(func_name);
```

Associated Errors

By default, for each bin, the sum of weights is computed at fill time. One can also call `TH1::Sumw2` to force the storage and computation of the sum of the square of weights per bin. If `Sumw2` has been called, the error per bin is computed as the `sqrt(sum of squares of weights)`, otherwise the error is set equal to the `sqrt (bin content)`. To return the error for a given bin number, do:

```
Double_t error = h->GetBinError(bin);
```

Fit Statistics

You can change the statistics box to display the fit parameters with the `TH1::SetOptFit(mode)` method. This mode has four digits.

Mode = `pcev` (default = 0111)

- `v` = 1 print name/values of parameters
- `e` = 1 print errors (if e=1, v must be 1)
- `c` = 1 print Chi-square/number of degrees of freedom
- `p` = 1 print probability

For example:

```
gStyle->SetOptFit(1011);
```

This prints the fit probability, parameter names/values, and errors.

6 A Little C++

This chapter introduces you to some useful insights into C++, to allow you to use of the most advanced features in ROOT. It is in no case a full course in C++.

Classes, Methods and Constructors

C++ extends C with the notion of class. If you're used to structures in C, a class is a `struct`, that is a group of related variables, which is extended with functions and routines specific to this structure (class). What is the interest? Consider a `struct` that is defined this way:

```
struct Line {
  float x1;
  float y1;
  float x2;
  float y2;
}
```

This structure represents a line to be drawn in a graphical window. (`x1,y1`) are the coordinates of the first point, (`x2,y2`) the coordinates of the second point.

In standard C, if you want to effectively draw such a line, you first have to define a structure and initialize the points (you can try this):

```
Line firstline;
firstline.x1 = 0.2;
firstline.y1 = 0.2;
firstline.x2 = 0.8;
firstline.y2 = 0.9;
```

This defines a line going from the point (0.2,0.2) to the point (0.8,0.9). To draw this line, you will have to write a function, say `LineDraw(Line l)` and call it with your object as argument:

```
LineDraw(firstline);
```

In C++, we would not do that. We would instead define a class like this:

```
class TLine {
      Double_t x1;
      Double_t y1;
      Double_t x2;
      Double_t y2;

TLine(int x1, int y1, int x2, int y2);
      void Draw();
}
```

Here we added two functions, that we will call methods or member functions, to the `TLine` class. The first method is used for initializing the line objects we would build. It is called a constructor.

The second one is the `Draw` method itself. Therefore, to build and draw a line, we have to do:

```
TLine l(0.2,0.2,0.8,0.9);
l.Draw();
```

The first line builds the object `l` by calling its constructor. The second line calls the `TLine::Draw()` method of this object. You don't need to pass any parameters to this method since it applies to the object `l`, which knows the coordinates of the line. These are internal variables `x1, y1, x2, y2` that were initialized by the constructor.

Inheritance and Data Encapsulation

Inheritance

We've defined a `TLine` class that contains everything necessary to draw a line. If we want to draw an arrow, is it so different from drawing a line? We just have to draw a triangle at one end. It would be very inefficient to define the class `TArrow` from scratch. Fortunately, inheritance allows a class to be defined from an existing class. We would write something like:

```
class TArrow : public TLine {
      int ArrowHeadSize;
      void Draw();
      void SetArrowSize(int arrowsize);
}
```

The keyword "`public`" will be explained later. The class `TArrow` now contains everything that the class `TLine` does, and a couple of things more, the size of the arrowhead and a function that can change it. The Draw method of `TArrow` will draw the head and call the draw method of `TLine`. We just have to write the code for drawing the head!

Method Overriding

Giving the same name to a method (remember: method = member function of a class) in the child class (`TArrow`) as in the parent (`TLine`) doesn't give any problem. This is called **overriding** a method. Draw in `TArrow` overrides Draw in `TLine`. There is no possible ambiguity since, when one calls the `Draw()` method; this applies to an object which type is known. Suppose we have an object **`l`** of type `TLine` and an object **`a`** of type `TArrow`. When you want to draw the line, you do:

```
l.Draw()
```

`Draw()` from `TLine` is called. If you do:

```
a.Draw()
```

`Draw()` from `TArrow` is called and the arrow `a` is drawn.

Data Encapsulation

We have seen previously the keyword "`public`". This keyword means that every name declared public is seen by the outside world. This is opposed to "`private`" which means only the class where the name was declared private could see this name. For example, suppose we declare in `TArrow` the variable `ArrowHeadSize` private.

```
private :
      int ArrowHeadSize;
```

Then, only the methods (=member functions) of `TArrow` will be able to access this variable. Nobody else will see it. Even the classes that we could derive from `TArrow` will not see it. On the other hand, if we declare the method `Draw()` as public, everybody will be able to see it and use it. You see that the character public or private doesn't depend of the type of argument. It can be a data member, a member function, or even a class.

For example, in the case of `TArrow`, the base class `TLine` is declared as public:

```
class TArrow : public TLine {
```

This means that all methods of `TArrow` will be able to access all methods of `TLine`, but this will be also true for anybody in the outside world. Of course, this is true provided that `TLine` accepts the outside world to see it's methods/data members. If something is declared private in `TLine`, nobody will see it, not even `TArrow` members, even if `TLine` is declared as a public base class.

What if `TLine` is declared "`private`" instead of "`public`"? Well, it will behave as any other name declared private in `TArrow`: only the data members and methods of `TArrow` will be able to access `TLine`, it's methods and data members, nobody else.

This may seem a little bit confusing and readers should read a good C++ book if they want more details. Especially since, besides public and private, a member can be protected.

Usually, one puts private the methods that the class uses internally, like some utilities classes, and that the programmer doesn't want to be seen in the outside world.

With "good" C++ practice (which we have tried to use in ROOT), all data members of a class are private. This is called data encapsulation and is one of the strongest advantages of Object Oriented Programming (OOP). Private data members of a class are not visible, except to the class itself. So, from the outside world, if one wants to access those data members, one should use so called "getters" and "setters" methods, which are special methods used only to get or set the data members. The advantage is that if the programmers want to modify the inner workings of their classes, they can do so without changing what the user sees. The user doesn't even have to know that something has changed (for the better, hopefully).

For example, in our `TArrow` class, we would have set the data member `ArrowHeadSize` private. The setter method is `SetArrowSize()`, we don't need a getter method:

```
class TArrow : public TLine {
private:
      int ArrowHeadSize;

public:
      void Draw();
      void SetArrowSize(int arrowsize);
}
```

To define an arrow object you call the constructor. This will also call the constructor of `TLine`, which is the parent class of `TArrow`, automatically. Then we can call any of the line or arrow public methods such as `SetArrowSize` and `Draw`.

```
root[] TArrow* myarrow = new TArrow(1,5,89,124);
root[] myarrow->SetArrowSize(10);
root[] myarrow->Draw();
```

Creating Objects on the Stack and Heap

To explain how objects are created on the stack and on the heap we will use the `Quad` class. You can find the definition in `$ROOTSYS/tutorials/Quad.h` and `Quad.cxx.`

The `Quad` class has four methods. The constructor and destructor, `Evaluate` which evaluates `ax**2 + bx +c , and Solve` which solves the quadratic equation `ax**2 + bx +c = 0.`

`Quad.h`:

```
class Quad {
      public:
      Quad(Float_t a, Float_t b, Float_t c);
      ~Quad();
      Float_t Evaluate(Float_t x) const;
      void Solve() const;
      private:
      Float_t fA;
      Float_t fB;
      Float_t fC;
};
```

Quad.cxx:

```
#include <iostream.h>
#include <math.h>
#include "Quad.h"

Quad::Quad(Float_t a, Float_t b, Float_t c) {
    fA = a;
    fB = b;
    fC = c;
}

Quad::~Quad() {
  cout << "deleting object with coeffts: "
       << fA << "," << fB << "," << fC << endl;
}

Float_t Quad::Evaluate(Float_t x) const {
  return fA*x*x + fB*x + fC;
}

void Quad::Solve() const {
  Float_t temp = fB*fB - 4.*fA*fC;
  if ( temp > 0. ) {
    temp = sqrt( temp );
    cout << "There are two roots: "
         << ( -fB - temp ) / (2.*fA)
         << " and "
         << ( -fB + temp ) / (2.*fA)
         << endl;
  } else {
    if ( temp == 0. ) {
      cout << "There are two equal roots: "
           << -fB / (2.*fA) << endl;
    } else {
      cout << "There are no roots" << endl;
    }
  }
}
```

Let's first look how we create an object. When we create an object by

```
root[] Quad my_object(1.,2.,-3.);
```

We are creating an object on the stack. A FORTRAN programmer may be familiar with the idea; it's not unlike a local variable in a function or subroutine. Although there are still a few old timers who don't know it, FORTRAN is under no obligation to save local variables once the function or subroutine returns unless the SAVE statement is used. If not then it is likely that FORTRAN will place them on the stack and they will "pop off" when the RETURN statement is reached.

To give an object more permanence it has to be placed on the heap.

```
root[] .L Quad.cxx
root[] Quad* my_objptr = new Quad(1., 2., -3.);
```

The second line declares a pointer to `Quad` called `my_objptr`. From the syntax point of view, this is just like all the other declarations we have seen so far, i.e. this is a stack variable. The value of the pointer is set equal to `new Quad(1., 2., -3.);`

`new`, despite its looks, is an operator and creates an object or variable of the type that comes next, `Quad` in this case, on the heap. Just as with stack objects it has to be initialized by calling its constructor. The syntax requires that the argument list follow the type. This one statement has brought two items into existence, one on the heap and one on the stack. The heap object will live until the delete operator is applied to it.

There is no FORTRAN parallel to a heap object; variables either come and go as control passes in and out of a function or subroutine, or, like a COMMON block variables, live for the lifetime of the program. However, most people in HEP who use FORTRAN will have experience of a memory manager and the act of creating a bank is a good equivalent of a heap object. For those who know systems like ZEBRA, it will come as a relief to learn that objects don't move, C++ does not garbage collect, so there is never a danger that a pointer to an object becomes invalid for that reason. However, having created an object, it is the user's responsibility to ensure that it is deleted when no longer needed, or to pass that responsibility onto to some other object. Failing to do that will result in a memory leak, one of the most common and most hard-to-find C++ bugs.

To send a message to an object via a pointer to it, you need to use the "->" operator e.g.:

```
root[] my_objptr->Solve();
```

Although we chose to call our pointer `my_objptr`, to emphasize that it is a pointer, heap objects are so common in an OO program that pointer names rarely reflect the fact - you have to be careful that you know if you are dealing with an object or its pointer! Fortunately, the compiler won't tolerate an attempt to do something like:

```
root[] my_objptr.Solve();
```

Although this is a permitted by the CINT shortcuts, it is one that you are *strongly* advised not to follow!

As we have seen, heap objects have to be accessed via pointers, whereas stack objects can be accessed directly. They can also be accessed via pointers:

```
root[] Quad stack_quad(1.,2.,-3.);
root[] Quad* stack_ptr = &stack_quad;
root[] stack_ptr->Solve();
```

Here we have a `Quad` pointer that has been initialized with the address of a stack object. Be very careful if you take the address of stack objects. As we shall see soon, they get deleted automatically, which could leave you with an illegal pointer. Using it will corrupt and may well crash the program!

It is time to look at the destruction of objects. Just as its constructor is called when it is created, so its destructor is called when it is destroyed. The compiler will provide a destructor that does nothing if none is provided. We will add one to our Quad class so that we can see when it gets called.

The destructor is named by the class but with the prefix ~ which is the C++ one's complement i.e. bit wise complement, and hence has destruction overtones! We declare it in the .h file and define it in the `.cxx` file. It does not do much except print out that it has been called (still a useful debug technique despite today's powerful debuggers!). Now run root, load the Quad class and create a heap object:

```
root[] .L Quad.cxx
root[] Quad* my_objptr = new Quad(1., 2., -3.);
```

To delete the object:

```
root[] delete my_objptr;
root[] my_objptr = 0;
```

You should see the print out from its destructor. Setting the pointer to zero afterwards isn't strictly necessary (and CINT does it automatically), but the object is no more, and any attempt to use the pointer again will, as has already been stated, cause grief.

So much for heap objects, but how do stack objects get deleted? In C++ a stack object is deleted as soon as control leaves the innermost compound statement that encloses it. So it is singularly futile to do something like:

```
root[] {  Quad my_object(1.,2.,-3.); }
```

CINT does not follow this rule; if you type in the above line you will not see the destructor message. As explained in the Script lesson, you can load in compound statements, which would be a bit pointless if everything disappeared as soon as it was loaded! Instead, to reset the stack you have to type:

```
root[] gROOT->Reset();
```

This sends the Reset message via the global pointer to the ROOT object, which, amongst its many roles, acts as a resource manager. Start ROOT again and type in the following:

```
root[] .L Quad.cxx
root[] Quad my_object(1.,2.,-3.);
root[] Quad* my_objptr = new Quad(4., 5., -6.);
root[] gROOT->Reset();
```

You will see that this deletes the first object but not the second. We have also painted ourselves into a corner, as `my_objptr` was also on the stack. This command will fail.

```
 root[] my_objptr->Solve();
```

CINT no longer knows what `my_objptr` is. This is a great example of a memory leak; the heap object exists but we have lost our way to access it. In general, this is not a problem. If any object will outlive the compound statement in which it was created then it will be pointed to by a more permanent pointer, which frequently is part of another heap object. See Resetting the Interpreter Environment in the chapter CINT the C++ Interpreter

7 CINT the C++ Interpreter

The subject of this chapter is CINT, ROOT's command line interpreter and script processor. First, we explain what CINT is and why ROOT uses it. Then CINT as the command line interpreter, the CINT commands, and CINT's extensions to C++ are discussed. CINT as the script interpreter is also explained and illustrated with several examples.

What is CINT?

CINT, which is pronounced C-int, is a C++ interpreter. An interpreter takes a program, in this case a C++ program, and carries it out by examining each instruction and in turn executing the equivalent sequence of machine language. For example, an interpreter translates and executes each statement in the body of a loop "n" times. It does not generate a machine language program. This may not be a good example, because most interpreters have become 'smart' about loop processing.

A compiler on the other hand, takes a program and makes a machine language executable. Once compiled the execution is very fast, which makes a compiler best suited for the case of "built once, run many times". For example, the ROOT executable is compiled occasionally and executed many times. It takes anywhere from 1 to 45 minutes to compile ROOT for the first time (depending on the CPU). Once compiled it runs very fast. On the average, a compiled program runs ten times faster than an interpreted one.

Because it takes much time to compile, using a compiler is cumbersome for rapid prototyping when one changes and rebuilds as often as every few minutes. An interpreter, optimized for code that changes often and runs a few times, is the perfect tool for this.

Most of the time, an interpreter has a separate scripting language, such as Python, IDL, and PERL, designed especially for interpretation, rather than compilation. However, the advantage of having one language for both is that once the prototype is debugged and refined, it can be compiled without translating the code to a compiled language.

CINT being a C++ interpreter is the tool for rapid prototyping and scripting in C++. It is a stand-alone product developed by Masaharu Goto. It's executable comes with the standard distribution of ROOT ($ROOTSYS/bin/cint), and it can also be installed separately from:

http://root.cern.ch/CINT.html

This page also has links to all the CINT documentation. The downloadable tar file contains documentation, the CINT executable, and many demo scripts, which are not included in the regular ROOT distribution.

Here is a list of CINT's main features:

- Supports K&R-C, ANSI-C, ANSI-C++
  CINT covers 80-90% of the K&R-C, ANSI-C and C++ language constructs. It supports multiple inheritance, virtual function, function overloading, operator overloading, default parameter, template, and much more. CINT is robust enough to interpret its own source code. CINT is not designed to be a 100% ANSI/ISO compliant C++ language processor. It is a portable scripting language environment, which is close enough to the standard C++.
- Interprets Large C/C++ source code
  CINT can handle huge C/C++ source code, and loads source files quickly. It can interpret its own, over 70,000 lines source code.
- Enables mixing Interpretation & Native Code
  Depending on the need for execution speed or the need for interaction, one can mix native code execution and interpretation. "makeCINT" encapsulates arbitrary C/C++ objects as a precompiled libraries. A precompiled library can be configured as a dynamically linked library. Accessing interpreted code and precompiled code can be done seamlessly in both directions.
- Provides a Single-Language solution
  CINT/makeCINT is a single-language environment. It works with any ANSI-C/C++ compiler to provide the interpreter environment on top of it.
- Simplifies C++
  CINT is meant to bring C++ to the non-software professional. C++ is simpler to use in the interpreter environment. It helps the non-software professional (the domain expert) to talk the same language as the software counterpart.
- Provides RTTI and a Command Line
  CINT can process C++ statements from command line, dynamically define/erase class definition and functions, load/unload source files and libraries. Extended Run Time Type Identification is provided, allowing you to explore unthinkable way of using C++.
- Has a Built-in Debugger and Class Browser
  CINT has a built-in debugger to debug complex C++ code. A text based class browser is part of the debugger.
- Is Portable
  CINT works on number of operating systems: HP-UX, Linux, SunOS, Solaris, AIX, Alpha-OSF, IRIX, FreeBSD, NetBSD, NEC EWS4800, NewsOS, BeBox, Windows-NT, Windows-9x, MS-DOS, MacOS, VMS, NextStep, Convex.

The ROOT Command Line Interface

Start up a ROOT session by typing ROOT at the system prompt.

```
hproot) [199] root
  *******************************************
  *                                         *
  *        W E L C O M E  to  R O O T       *
  *                                         *
  *   Version   2.25/02      21 August 2000 *
  *                                         *
  *  You are welcome to visit our Web site  *
  *          http://root.cern.ch            *
  *                                         *
  *******************************************

CINT/ROOT C/C++ Interpreter version 5.14.47, Aug 12 2000
Type ? for help. Commands must be C++ statements.
Enclose multiple statements between { }.
```

Now create a `TLine` object:

```
root [] TLine l
root [] l.Print()
TLine  X1=0.000000 Y1=0.000000 X2=0.000000 Y2=0.000000
root [] l.SetX1(10)
root [] l.SetY1(11)
root [] l.Print()
TLine  X1=10.000000 Y1=11.000000 X2=0.000000 Y2=0.000000
root [] .g
...
0x4038f080 class TLine l , size=40
  0x0        protected: Double_t fX1 //X of 1st point
  0x0        protected: Double_t fY1 //Y of 1st point
  0x0        protected: Double_t fX2 //X of 2nd point
  0x0        protected: Double_t fY2 //Y of 2nd point
  0x0        private: static class TClass* fgIsA
```

Here we note:

- Terminating `;` not required (see the section ROOT/CINT Extensions to C++).
- Emacs style command line editing.
- Raw interpreter commands start with a . (dot).

```
root [] .class TLine
==================================================
class TLine //A line segment
 size=0x28
List of base class-------------------------------
0x0        public: TObject //Basic ROOT object
0xc        public: TAttLine //Line attributes
List of member variable--------------------------
Defined in TLine
0x0        protected: Double_t fX1 //X of 1st point
0x0        protected: Double_t fY1 //Y of 1st point
0x0        protected: Double_t fX2 //X of 2nd point
0x0        protected: Double_t fY2 //Y of 2nd point
0x0        private: static class TClass* fgIsA
List of member function--------------------------
Defined in TLine
filename   line:size busy function type and name
(compiled) 0:0    0 public: class TLine TLine(void);
(compiled) 0:0    0 public: Double_t GetX1(void);
(compiled) 0:0    0 public: Double_t GetX2(void);
(compiled) 0:0    0 public: Double_t GetY1(void);
(compiled) 0:0    0 public: Double_t GetY2(void);
...
...
(compiled) 0:0 public: virtual void SetX1(Double_t x1);
(compiled) 0:0 public: virtual void SetX2(Double_t x2);
(compiled) 0:0 public: virtual void SetY1(Double_t y1);
(compiled) 0:0 public: virtual void SetY2(Double_t y2);
(compiled) 0:0    0 public: void ~TLine(void);
root [] l.Print(); > test.log
root [] l.Dump(); >> test.log
root [] ?
```

Here we see:

- Use `.class` as quick help and reference
- Unix like I/O redirection (`;` is required before `>`)
- Use `?` to get help on all ``raw'' interpreter commands

Now lets execute a multi-line command:

```
root [] {
end with '}'> TLine l;
end with '}'> for (int i = 0; i < 5; i++) {
end with '}'>    l.SetX1(i);
end with '}'>    l.SetY1(i+1);
end with '}'>    l.Print();
end with '}'> }
end with '}'> }
TLine  X1=0.000000 Y1=1.000000 X2=0.000000 Y2=0.000000
TLine  X1=1.000000 Y1=2.000000 X2=0.000000 Y2=0.000000
TLine  X1=2.000000 Y1=3.000000 X2=0.000000 Y2=0.000000
TLine  X1=3.000000 Y1=4.000000 X2=0.000000 Y2=0.000000
TLine  X1=4.000000 Y1=5.000000 X2=0.000000 Y2=0.000000
root [] .q
```

Here we note:

- A multi-line command starts with a `{` and ends with a `}`.
- Every line has to be correctly terminated with a `;` (like in "real" C++).
- All objects are created in *global* scope.
- There is no way to back up, you are better off writing a script.
- Use `.q` to exit root.

The ROOT Script Processor

ROOT script files contain pure C++ code. They can contain a simple sequence of statements like in the multi command line example given above, but also arbitrarily complex class and function definitions.

Un-named Scripts

Lets start with a script containing a simple list of statements (like the multi-command line example given in the previous section). This type of script must start with a `{` and end with a `}`and is called an un-named script. Assume the file is called `script1.C`

```
{
#include <iostream.h>

   cout << " Hello" << endl;
   float x = 3.;
   float y = 5.;
   int   i = 101;
   cout <<" x = "<<x<<" y = "<<y<<" i = "<<i<< endl;
}
```

To execute the stream of statements in `script1.C` do:

```
root [] .x script1.C
```

This loads the contents of file `script1.C` and executes all statements in the interpreter's *global scope*.

One can re-execute the statements by re-issuing "`.x script1.C`" (since there is no function entry point).

Scripts are searched for in the `Root.MacroPath` as defined in your `.rootrc` file. To check which script is being executed use:

```
root [] .which script1.C
/home/rdm/root/./script1.C
```

Named Scripts

Lets change the un-named script to a named script. Copy file `script1.C` to `script2.C` and add a function statement. Like this:

```
#include <iostream.h>

int main()
{
   cout << " Hello" << endl;
   float x = 3.;
   float y = 5.;
   int   i= 101;
   cout <<" x = "<<x<<" y = "<<y<<" i = "<<i<<endl;
   return 0;
}
```

Notice that **no** surrounding `{ }` are required in this case. To execute function `main()` in `script2.C` do:

```
root [] .L script2.C   // load script in memory
root [] main()  // execute entry point main
 Hello
 x = 3 y = 5 i = 101
(int)0
root [] main()  // execute main() again
 Hello
 x = 3 y = 5 i = 101
(int)0
root [] .func   // list all functions known by CINT
filename       line:size busy function type and name
...
script2.C          4:9   0 public: int main();
```

The last command shows that `main()` has been loaded from file `script2.C`, that the function `main()` starts on line 4 and is 9 lines long. Notice that once a function has been loaded it becomes part of the system just like a compiled function.

Now we copy file `script2.C` to `script3.C` and change the function name from `main()` to `script3(int j = 10)`:

```
#include <iostream.h>
int script3(int j = 10)
{
   cout << " Hello" << endl;
   float x = 3.;
   float y = 5.;
   int   i = j;
   cout <<" x = "<<x<<" y = "<<y<<" i = "<<i<<endl;
   return 0;
}
```

To execute `script3()` in `script3.C` type:

```
root [] .x script3.C(8)
```

This loads the contents of file `script3.C` and executes entry point `script3(8)`. Note that the above only works when the filename (minus extension) and function entry point are both the same. Function `script3()` can still be executed multiple times:

```
root [] script3()
 Hello
 x = 3 y = 5 i = 10
(int)0
root [] script3(33)
 Hello
 x = 3 y = 5 i = 33
(int)0
```

In a named script, the objects created on the stack are deleted when the function exits. For example, this scenario is very common. You create a histogram in a named script on the stack. You draw the histogram, but when the function exits the canvas is empty and the histogram disappeared.

To avoid histogram from disappearing you can create it on the heap (by using new). This will leave the histogram object intact, but the pointer in the named script scope will be deleted.

Since histograms (and trees) are added to the list of objects in the current directory, you can always retrieve them to delete them if needed.

```
root[] TH1F *h = (TH1F*)gDirectory->Get("myHist");
```

or

```
root[] TH1F *h = (TH1F*)gDirectory->GetList()->FindObject("myHist");
```

In addition, histograms and trees are automatically deleted when the current directory is closed. This will automatically take care of the clean up. See chapter Input/Output.

Resetting the Interpreter Environment

Variables created on the command line and in un-named scripts are in the interpreter's global scope, which makes the variables created in un-named scripts available on the command line event after the script is done executing. This is the opposite of a named script where the stack variables are deleted when the function in which they are defined has finished execution.

When running an un-named script over again and this is frequently the case since un-named scripts are used to prototype, one should reset the global environment to clear the variables. This is done by calling `gROOT->Reset()`. It is good practice, and you will see this in the examples, to begin an un-named script with `gROOT->Reset`. It clears the global scope to the state just before executing the previous script (not including any logon scripts).

The `gROOT->Reset()` calls the destructor of the objects if the object was created on the stack. If the object was created on the heap (via new) it is not deleted, but the variable is no longer associated with it. Creating variables on the heap in un-named scripts and calling `gROOT->Reset()` without you calling the destructor explicitly will cause a memory leak.

This may be surprising, but it follows the scope rules. For example, creating an object on the heap in a function (in a named script) without explicitly deleting it will also cause a memory leak. Since when exiting the function only the stack variables are deleted.

The code below shows `gROOT->Reset` calling the destructor for the stack variable, but not for the heap variable. In the end, neither variable is available, but the memory for the heap variable is not released.

Here is an example.

```
root [] gDebug = 1
 (const int)1
root [] TFile stackVar("stack.root","RECREATE")
   TKey Writing 86 bytes at address 64 for ID= stack.root Title=
root [] TFile *heapVar = new TFile("heap.root", "RECREATE")
   TKey Writing 84 bytes at address 64 for ID= heap.root Title=
```

We turn on `Debug` to see what the subsequent calls are doing. Then we create two variables, one on the stack and one on the heap.

```
root [] gROOT->Reset()
   TKey Writing 48 bytes at address 150 for ID= stack.root Title=
   TKey Writing 54 bytes at address 198 for ID= stack.root Title=
TFile dtor called for stack.root
TDirectory dtor called for stack.root
```

When we call `gROOT->Reset`, CINT tells us that the destructor is called for the stack variable, but it doesn't mention the heap variable.

```
root [] stackVar
Error: No symbol stackVar in current scope
FILE:/var/tmp/faaa01jWe_cint LINE:1
*** Interpreter error recovered ***
root [] heapVar
Error: No symbol heapVar in current scope
FILE:/var/tmp/gaaa01jWe_cint LINE:1
*** Interpreter error recovered ***
```

Neither variable is available in after the call to reset.

```
root [] gROOT->FindObject("stack.root")
(class TObject*)0x0
root [] gROOT->FindObject("heap.root")
(class TObject*)0x106bfb30
```

The object on the stack is deleted and shows a null pointer when we do a `FindObject`. However, the heap object is still around and taking up memory.

A Script Containing a Class Definition

Lets create a small class `TMyClass` and a derived class `TChild`. The virtual `TMyClass::Print()` method is overridden in `TChild`. Save this in file called `script4.C`.

```
#include <iostream.h>

class TMyClass {

private:
   float   fX;     //x position in centimeters
   float   fY;     //y position in centimeters

public:
   TMyClass() { fX = fY = -1; }
   virtual void Print() const;
   void         SetX(float x) { fX = x; }
   void         SetY(float y) { fY = y; }
};

void TMyClass::Print() const  // parent print method
{
   cout << "fX = " << fX << ", fY = " << fY << endl;
}


//-----------------------------------------------------------
class TChild : public TMyClass {
public:
   void Print() const;
};

void TChild::Print() const  // child print metod
{
   cout << "This is TChild::Print()" << endl;
   TMyClass::Print();
}
```

To execute `script4.C` do:

```
root [] .L script4.C
root [] TMyClass *a = new TChild
root [] a->Print()
This is TChild::Print()
fX = -1, fY = -1
root [] a->SetX(10)
root [] a->SetY(12)
root [] a->Print()
This is TChild::Print()
fX = 10, fY = 12
root [] .class TMyClass
=====================================================
class TMyClass
 size=0x8 FILE:script4.C LINE:3
List of base class-----------------------------------
List of member variable------------------------------
Defined in TMyClass
0x0        private: float fX
0x4        private: float fY
List of member function------------------------------
Defined in TMyClass
filename       line:size busy function type and name
script4.C         16:5    0 public: class TMyClass
                                       TMyClass(void);
script4.C         22:4    0 public: void Print(void);
script4.C         12:1    0 public: void SetX(float x);
script4.C         13:1    0 public: void SetY(float y);
root [] .q
```

As you can see an interpreted class behaves just like a compiled class.

There are some limitations for a class created in a script:

1. They cannot inherit from `TObject`. Currently the interpreter cannot patch the virtual table of compiled objects to reference interpreted objects.
2. Because the I/O is encapsulated in `TObject` and a class defined in a script can not inherit from `TObject`, it can not be written to a ROOT file.

For ways to add a class with a shared library and with ACLiC, see the chapter: "Adding a Class"

Debugging Scripts

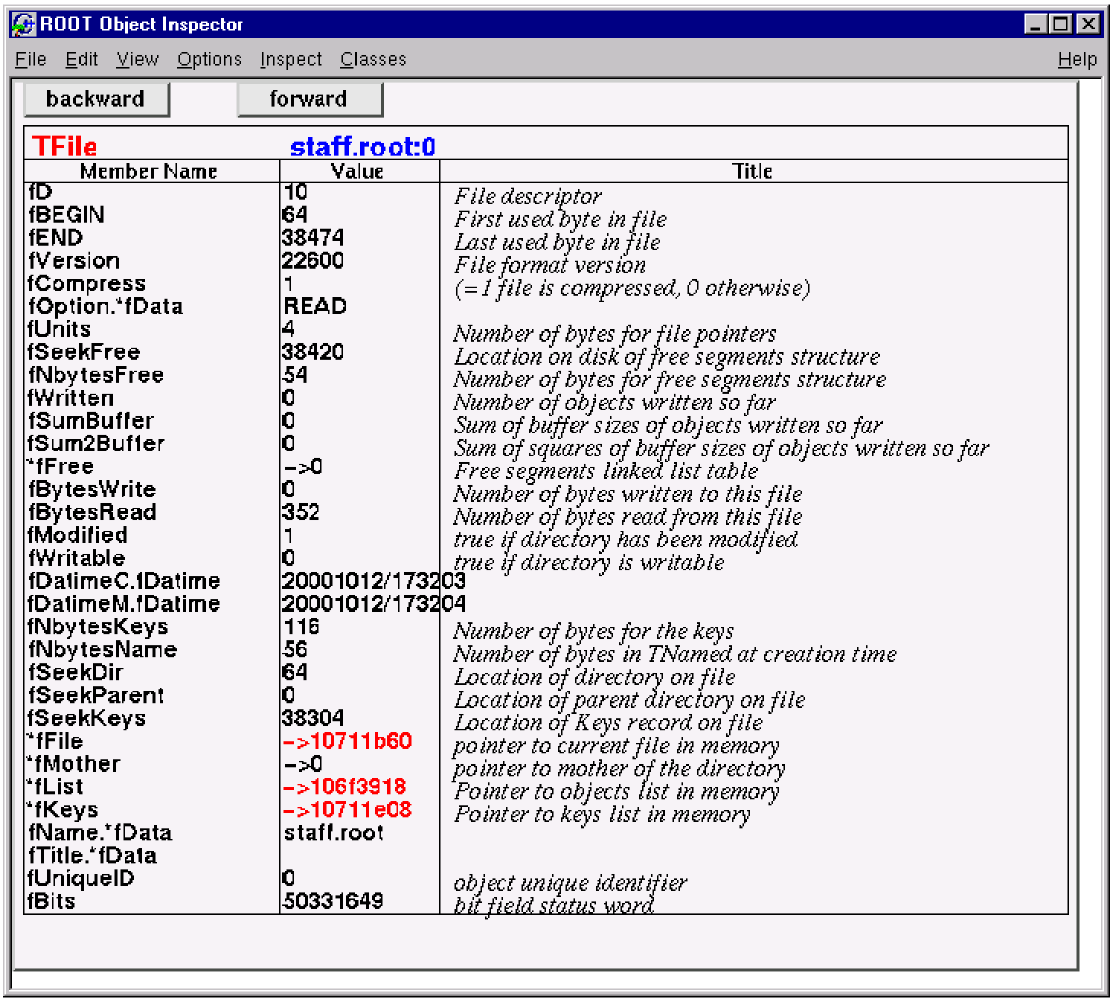
A powerful feature of CINT is the ability to debug interpreted functions by means of setting breakpoints and being able to single step through the code and print variable values on the way. Assume we have `script4.C` still loaded, we can then do:

```
root [] .b TChild::Print
Break point set to line 26 script4.C
root [] a.Print()

26   TChild::Print() const
27   {
28      cout << "This is TChild::Print()" << endl;
FILE:script4.C LINE:28 cint> .s

311  operator<<(ostream& ostr,G__CINT_ENDL& i)
{return(endl(ostr));
FILE:iostream.h LINE:311 cint> .s
}
This is TChild::Print()

29      MyClass::Print();
FILE:script4.C LINE:29 cint> .s

16   MyClass::Print() const
17   {
18      cout << "fX = " << fX << ", fY = " << fY << endl;
FILE:script4.C LINE:18 cint> .p fX
(float)1.000000000000e+01
FILE:script4.C LINE:18 cint> .s

311  operator<<(ostream& ostr,G__CINT_ENDL& i)
{return(endl(ostr));
FILE:iostream.h LINE:311 cint> .s
}
fX = 10, fY = 12

19   }

30   }

2    }
root [] .q
```

Inspecting Objects

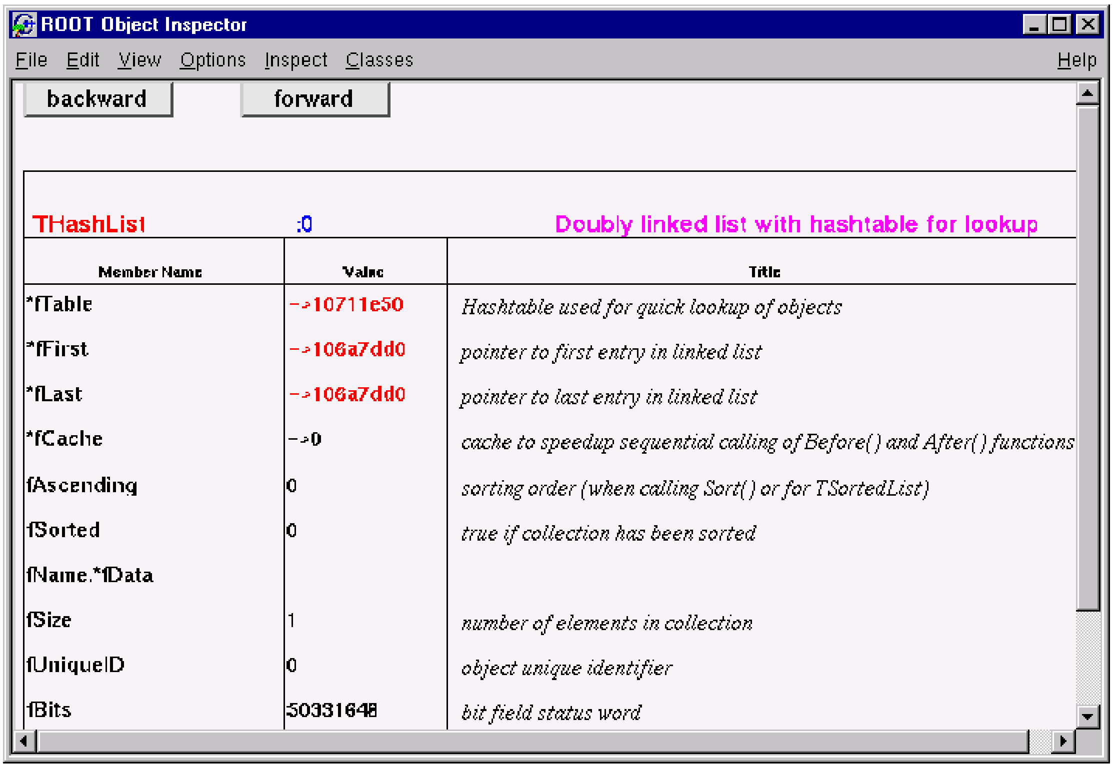
An object of a class inheriting from `TObject` can be inspected, with the Inspect method. The `TObject::Inspect` method creates a window listing the current values of the objects members. For example, this is a picture of `TFile`.

```
root[] TFile f("staff.root")
root[] f.Inspect()
```



Member Name	Value	Title
fD	10	File descriptor
fBEGIN	64	First used byte in file
fEND	38474	Last used byte in file
fVersion	22600	File format version
fCompress	1	(=1 file is compressed, 0 otherwise)
fOption.*fData	READ	
fUnits	4	Number of bytes for file pointers
fSeekFree	38420	Location on disk of free segments structure
fNbytesFree	54	Number of bytes for free segments structure
fWritten	0	Number of objects written so far
fSumBuffer	0	Sum of buffer sizes of objects written so far
fSum2Buffer	0	Sum of squares of buffer sizes of objects written so far
*fFree	->0	Free segments linked list table
fBytesWrite	0	Number of bytes written to this file
fBytesRead	352	Number of bytes read from this file
fModified	1	true if directory has been modified
fWritable	0	true if directory is writable
fDatimeC.fDatime	20001012/173203	
fDatimeM.fDatime	20001012/173204	
fNbytesKeys	116	Number of bytes for the keys
fNbytesName	56	Number of bytes in TNamed at creation time
fSeekDir	64	Location of directory on file
fSeekParent	0	Location of parent directory on file
fSeekKeys	38304	Location of Keys record on file
*fFile	->10711b60	pointer to current file in memory
*fMother	->0	pointer to mother of the directory
*fList	->106f3918	Pointer to objects list in memory
*fKeys	->10711e08	Pointer to keys list in memory
fName.*fData	staff.root	
fTitle.*fData		
fUniqueID	0	object unique identifier
fBits	50331649	bit field status word

You can see the pointers are in red and can be clicked on to follow the pointer to the object. For example, here we clicked on `fKeys`, the list of keys in memory.



If you clicked on `fList`, the list of objects in memory and there were none, no new canvas would be shown.

On top of the page are the navigation buttons to see the previous and next screen.

ROOT/CINT Extensions to C++

In the next example, we demonstrate three of the most important extensions ROOT/CINT makes to C++. Start ROOT in the directory `$ROOTSYS/tutorials` (make sure to have first run `".x hsimple.C"`):

```
root [] f = new TFile("hsimple.root")
(class TFile*)0x4045e690
root [] f.ls()
TFile**         hsimple.root
 TFile*         hsimple.root
  KEY: TH1F     hpx;1   This is the px distribution
  KEY: TH2F     hpxpy;1 py ps px
  KEY: THProfile        hprof;1 Profile of pz versus px
  KEY: TNtuple  ntuple;1        Demo ntuple
root [] hpx.Draw()
NULL
Warning in <MakeDefCanvas>: creating a default canvas with name
c1
root [] .q
```

The **first** command shows the first extension; the declaration of `f` may be omitted when **"**`new`**"** is used. CINT will correctly create `f` as pointer to object of class `TFile`.

The **second** extension is shown in the second command. Although `f` is a pointer to `TFile` we don't have to use the pointer de-referencing syntax "`->`" but can use the simple "`.`" notation.

The **third** extension is more important. In case CINT cannot find an object being referenced, it will ask ROOT to search for an object with an identical name in the search path defined by `TROOT::FindObject()`. If ROOT finds the object, it returns CINT a pointer to this object and a pointer to its class definition and CINT will execute the requested member function. This shortcut is quite natural for an interactive system and saves much typing. In this example, ROOT searches for `hpx` and finds it in `simple.root`.

The **fourth** is shown below. There is no need to put a semicolon at the end of a line. The difference between having it and leaving it off is that when you leave it off the return value of the command will be printed on the next line. For example:

```
root[] 23+5  // no semicolon prints the return value
(int)28
root[] 23+5; // semicolon no return value is printed
root[]
```

Be aware that these extensions do not work when the interpreter is replaced by a compiler. Your code will not compile, hence when writing large scripts, it is best to stay away from these shortcuts. It will save you from having problems compiling your scripts using a real C++ compiler.

ACLiC - The Automatic Compiler of Libraries for CINT

Instead of having CINT interpret your script there is a way to have your scripts compiled, linked and dynamically loaded using the C++ compiler and linker. The advantage of this is that your scripts will run with the speed of compiled C++ and that you can use language constructs that are not fully supported by CINT. On the other hand, you cannot use any CINT shortcuts (see CINT extensions) and for small scripts, the overhead of the compile/link cycle might be larger than just executing the script in the interpreter.

ACLiC will build a CINT dictionary and a shared library from your C++ script, using the compiler and the compiler options that were used to compile the ROOT executable. You do not have to write a makefile remembering the correct compiler options, and you do not have to exit ROOT.

Usage

Before you can compile your interpreted script you need to add include statements for the classes used in the script. Once you did that, you can build and load a shared library containing your script. To load it, use the `.L` command and append the file name with a `"+"`.

```
root [] .L MyScript.C+
root [] .files
…
…
*file="/home/./MyScript.so"
```

The newly created shared library is named after the script file name and has a `.so` extension. If we execute a `.files` command we can see the newly created shared library is in the list of loaded files.

When a + command is executed as above the shared library is rebuilt if the date of the script file has changed. Note that it does not automatically check the time stamp of the include files. To ensure that the shared library is rebuilt you can use the ++ syntax:

```
root[] .L MyScript.C++
```

To build, load, and execute the function with the same name as the file you can use the .x command. This is the same as executing a named script. You can have parameters and use .x or .X. The only difference is you need to append a + or a ++.

```
root[] .x MyScript.C+ (4000)
Creating shared library
/home/./MyScript.so
```

The alternative to `.L` is to use `gROOT::LoadMacro`. For example, in one script you can use ACLiC to compile and load another script.

```
gROOT->LoadMacro("MyScript.C+")
gROOT->LoadMacro("MyScript.C++")
```

+ and ++ have the same meaning as described above. You can also use the `gROOT::Macro` method to load and execute the script.

```
gROOT->Macro("MyScript.C++")
```

NOTE: You should not call ACLiC with a script that has a function called `main()`. When ACLiC calls `rootcint` with a function called `main` it tries to add every symbol it finds while parsing the script and the header files to the dictionary. This includes the system header files and the ROOT header files. This will result in duplicate entries at best and crashes at worst, because some classes in ROOT needs special attention before they can be added to the dictionary.

Intermediate Steps and Files

ACLiC executes two steps and a third one if needed. These are:

- Calling `rootcint` to create a CINT dictionary. `rootcint` is a ROOT specific version of `makecint`, CINT's generic dictionary generator.
- Calling the compiler to build the shared library from the script
- If there are errors, it calls the compiler to build a dummy executable to clearly report unresolved symbols.

ACLiC makes a shared library with a CINT dictionary containing the classes and functions declared in the script. It also adds the classes and functions declared in included files with the same name as the script file and any of the following extensions: `.h, .hh, .hpp, .hxx, .hPP, .hXX`. This means you cannot combine scripts from different files into one library by using #include statements; you will need to compile each script separately. In a future release, we plan to add the global variables declared in the script to the dictionary also. If you are curious about the specific calls, you can raise the ROOT debug level (`gDebug = 5`). ACLiC will print the three steps.

Moving between Interpreter and Compiler

The best way to develop portable scripts is to make sure you can always run them with both, the interpreter and with ACLiC. To do so, do not use the CINT extensions and program around the CINT limitations. When it is not possible or desirable to program around the CINT limitations, you can use the C preprocessor symbols defined for CINT and `rootcint`.

The preprocessor symbol `__CINT__` is defined for both CINT and `rootcint`. The symbol `__MAKECINT__` is only defined in `rootcint`.

Use **`!defined(__CINT__) || defined(__MAKECINT__)`** to bracket code that needs to seen by the compiler and `rootcint`, but will be invisible to the interpreter.

Use **`!defined(__CINT__)`** to bracket code that should be seen only by the compiler and not by CINT or `rootcint`.

For example, the following will hide the declaration and initialization of the array `gArray` from both CINT and `rootcint`.

```
#if !defined(__CINT__)
int gArray[] = { 2, 3, 4};
#endif
```

Because ACLiC calls `rootcint` to build a dictionary, the declaration of `gArray` will not be included in the dictionary, and consequently, `gArray` will not be available at the command line even if ACLiC is used. CINT and `rootcint` will ignore all statements between the "`#if !defined (__CINT__)`" and "`#endif`". If you want to use `gArray` in the same script as its declaration, you can do so. However, if you want use the script in the interpreter you have to bracket the usage of `gArray` between `#if's`, since the definition is not visible.

If you add the following preprocessor statements, `gArray` will be visible to `rootcint` but still not visible to CINT. If you use ACLiC, `gArray` will be available at the command line and be initialized properly by the compiled code.

```
#if !defined(__CINT__)
int gArray[] = { 2, 3, 4};
#elif defined(__MAKECINT__)
int gArray[];
#endif
```

We recommend you always write scripts with the needed include statements. In most cases, the script will still run with the interpreter. However, a few header files are not handled very well by CINT.

These types of headers can be included in interpreted and compiled mode:

- The subset of standard C/C++ headers defined in `$ROOTSYS/cint/include.`
- Headers of classes defined in a previously loaded library (including ROOT's own). The defined class must have a name known to ROOT (i.e. a class with a ClassDef).

A few headers will cause problems when they are included in interpreter mode, because they are already included by the interpreter itself. In general, the interpreter needs to know whether to use the interpreted or compiled version. The mode of the definition needs to match the mode of the reference.

Here are the cases that need to be excluded in interpreted mode, but included for `rootcint`. Bracket these with :
`!defined(__CINT__) || defined(__MAKECINT__)`

- All CINT headers, see `$ROOTSYS/cint/inc`
- Headers with classes named other than the file name. For example: `RType.h` and `GuiTypes.h`.
- Headers with a class defined in a libraries before the library is loaded. For example: having a `#include "TLorenzVector.h` before `gSystem->Load("libPhysics").`
  This will also cause problems when compiling the script, but a clear error message will be given. With the interpreter it may core dump. Bracket these type of include statements with `#if !defined (__CINT__),` this will print an error in both modes.

Hiding header files from `rootcint` that are necessary for the compiler but optional for the interpreter can lead to a subtle but fatal errors. For example:

```
#ifndef __CINT__
#include "TTree.h"
#else
class TTree;
#endif

class subTree : public TTree {
};
```

In this case, `rootcint` does not have enough information about the `TTree` class to produce the correct dictionary file. If you try this, `rootcint` and compiling will be error free, however, instantiating a `subTree` object from the CINT command line will cause a fatal error.

In general it is recommended to let `rootcint` see as many header files as possible.

Setting the Include Path

You can get the include path by typing:

```
root [] .include
```

You can append to the include path by typing:

```
root [] .include "-I$HOME/mypackage/include "
```

In a script you can set the include path:

```
gSystem->SetIncludePath (" -I$HOME/mypackage/include ")
```

The `$ROOTSYS/include` directory is automatically appended to the include path, so you don't have to worry about including it, however if you have already added a path, this command will overwrite it.

8 Graphics and the Graphical User Interface

Graphical capabilities of ROOT range from 2D objects (lines, polygons, arrows) to various plots, histograms, and 3D graphical objects. In this chapter, we are going to focus on principals of graphics and 2D objects. Plots and histograms are discussed in a chapter of their own.

Drawing Objects

In ROOT, most objects derive from a base class `TObject`. This class has a virtual method `Draw()` so all objects are supposed to be able to be "drawn".

The basic whiteboard on which an object is drawn is called a canvas (defined by the class `TCanvas`). If several canvases are defined, there is only one active at a time. One draws an object in the active canvas by using the statement:

```
object.Draw()
```

This instructs the object "`object`" to draw itself. If no canvas is opened, a default one (named "`c1`") is instantiated and drawn. Thy the following commands:

```
root [] TLine a (0.1,0.1,0.6,0.6)
root [] a.Draw()
<TCanvas::MakeDefCanvas>: created default TCanvas with name
c1
```

The first statement defines a line and the second one draws it. A default canvas is drawn since there was no opened one.

Interacting with Graphical Objects

When an object is drawn, one can interact with it. For example, the line drawn in the previous paragraph may be moved or transformed. One very important characteristic of ROOT is that transforming an object on the screen will also transform it in memory. One actually interacts with the real object, not with a copy of it on the screen. You can try for instance to look at the starting X coordinate of the line:

```
root[] a.GetX1()
(double)1.000000000e-1
```

X1 is the x value of the starting coordinate given in the definition above. Now move it interactively by clicking with the left mouse button in the line's middle and try to do again

```
root[] a.GetX1()
(Double_t)1.31175468483816005e-01
```

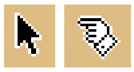
You do not obtain the same result as before, the coordinates of 'a' have changed. As said, interacting with an object on the screen changes the object in memory.

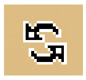
Moving, Resizing and Modifying Objects

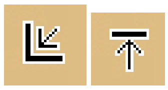
Changing the graphic objects attributes can be done with the GUI or programmatically. First, let's see how it is done in the GUI.

The Left Mouse Button

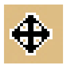
As was just seen moving or resizing an object is done with the left mouse button. The cursor changes its shape to indicate what may be done:

Point the object or one part of it: 

Rotate: 

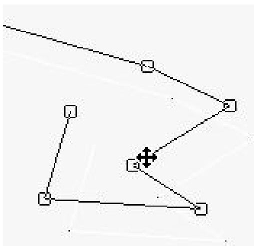
Resize (exists also for the other directions): 

Enlarge (used for text): 

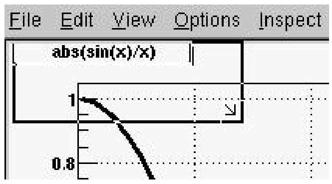
Move: 

Here are some examples of

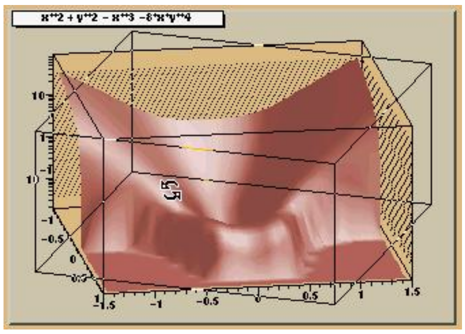
Moving:



Resizing:



Rotating:



With C++ Statements (Programmatically)

How would one move an object in a script? Since there is a tight correspondence between what is seen on the screen and the object in memory, changing the object changes it on the screen.

For example, try to do:

```
root[] a.SetX1(0.9)
```

This should change one of the coordinates of our line, but nothing happens on the screen. Why is that? In short, the canvas is not updated with each change for performance reasons. See the sub section on: "Updating the Pad" in the next section.

Selecting Objects

The Middle Mouse Button

Objects in a canvas, as well as in a pad, are stacked on top of each other in the order they were drawn. Some objects may become "active" objects, which means they are reordered to be on top of the others. To interactively make an object "active", you can use the middle mouse button. In case of canvases or pads, the border becomes highlighted when it is active.

With C++ Statements (Programmatically)

Frequently we want to draw in different canvases or pads. By default, the objects are drawn in the active canvas. To activate a canvas you can use the "`TPad::cd()`" method.

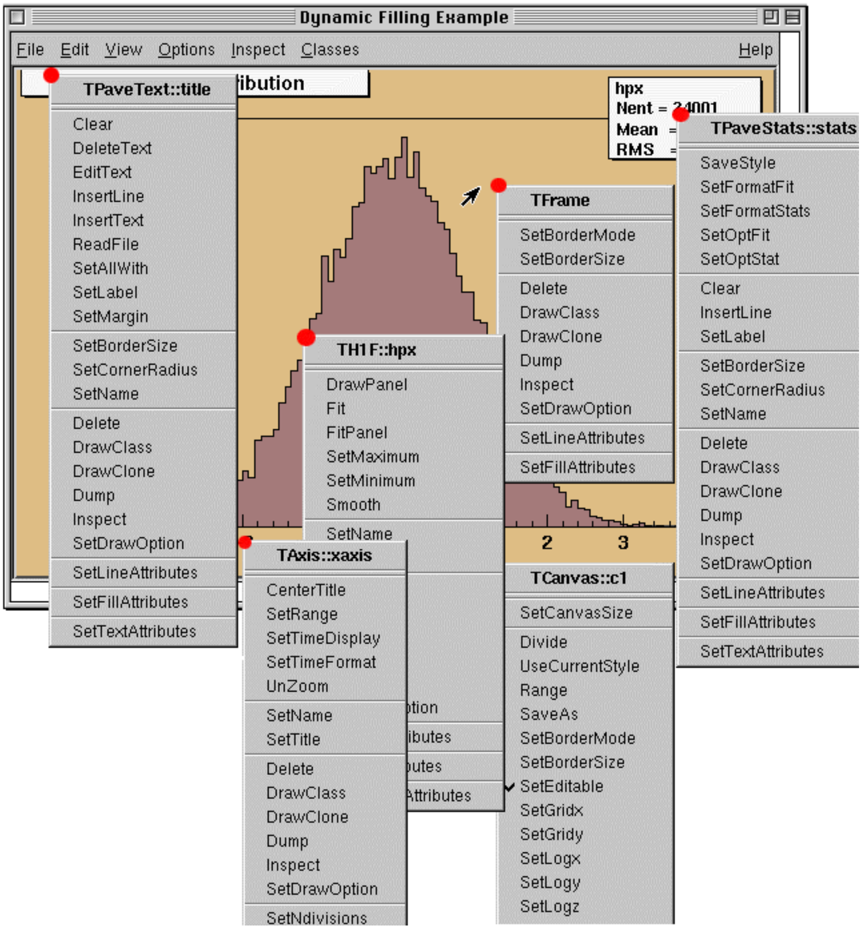
```
root[] c1->cd()
```

Context Menus: the Right Mouse Button

The context menus are a way to interactively call certain methods of an object. When designing a class, the programmer can add methods to the context menu of the object by making minor changes to the header file.

Using Context Menus

On a ROOT canvas, you can right-click on any object and see the context menu for it. The script `hsimple.C` draws a histogram. The image below shows the context menus for some of the objects on the canvas.



This picture shows that drawing a simple histogram involves as many as seven objects.

When selecting a method from the context menu and that method has options, the user will be asked for numerical values or strings to fill in the option. For example, `TAxis::SetTitle` will prompt you for a string to use for the axis title.

Structure of the Context Menus

The curious reader will have noticed that each entry in the context menu corresponds to a method of the class.

Look for example to the menu named `TAxis::xaxis`. `xaxis` is the name of the object and `TAxis` the name of its class. If we look at the list of `TAxis` methods, for example in http://www.root.ch/root/html/TAxis.html, we see the methods `SetTimeDisplay` and `UnZoom`, which appear also in the context menu.

There are several divisions in the context menu, separated by lines. The top division is a list of the class methods; the second division is a list of the parent class methods. The subsequent divisions are the methods of multiple parent classes in case of multiple inheritance.

For example, see the `TPaveText::title context menu`. A `TPaveText` inherits from `TAttLine`, which has the method `SetLineAttributes()`.

Adding Context Menus for a Class

For a method to appear in the context menu of the object it has to be marked by `// *MENU*` in the header file. Below is the line from `TAttLine.h` that adds the `SetLineAttribute` method to the context menu.

```
virtual void     SetLineAttributes(); // *MENU*
```

Nothing else is needed, since CINT knows the classes and their methods. It takes advantage of that to create the context menu on the fly when the object is clicking on.

If you click on an axis, ROOT will ask the interpreter what are the methods of the `TAxis` and which ones are set for being displayed in a context menu.

Now, how does the interpreter know this? Remember, when you build a class that you want to use in the ROOT environment, you use `rootcint` that builds the so-called stub functions and the dictionary. These functions and the dictionary contain the knowledge of the used classes. To do this, `rootcint` parses all the header files.

ROOT has defined some special syntax to inform CINT of certain things, this is done in the comments so that the code still compiles with a C++ compiler.

For example, you have a class with a `Draw()` method, which will display itself. You would like a context menu to appear when on clicks on the image of an object of this class. The recipe is the following:

1. The class has to contain the `ClassDef/ClassImp` macros
2. For each method you want to appear in the context menu, put a comment after the declaration containing `*MENU*` or `*TOGGLE*` depending on the behavior you expect. One usually uses `Set` methods (setters).

For example:

```
class MyClass : public TObject
{
private :
   int      fV1;   // first variable
   double   fV2;   // second variable
public :
   int    GetV1() {return fV1;}
   double GetV2() {return fV2;}
   void   SetV1(int x1) { fV1 = x1;}      // *MENU*
   void   SetV2(double d2) { fV2 = d2;}  // *MENU*
   void   SetBoth(int x1, double d2) {fV1 = x1; fV2 = d2;}

  ClassDef (MyClass,1)
}
```

The *TOGGLE* comment is used to toggle a boolean data field. In that case, it is safe to call the data field fMyBool where MyBool is the name of the setter SetMyBool. Replace MyBool with your own boolean variable.

3. You can specify arguments and the data members in which to store the arguments.

For example:

```
void SetXXX(Int_t x1, Float_t y2); //*MENU* *ARGS={x1=>fV1}
```

This statement is in the comment field, after the *MENU*. If there is more than one argument, these arguments are separated by commas, where fX1 and fY2 are data fields in the same class.

```
void SetXXX(Int_t x1, Float_t y2); //*MENU* *ARGS={x1=>fX1,y2=>fY2}
```

If the arguments statement is present, the option dialog displayed when selecting SetXXXfield will show the values of variables. We indicate to the system which argument corresponds to which data member of the class.

Executing Events when a Cursor passes on top of an Object

This paragraph is for class designers. When a class is designed, it is often desirable to include drawing methods for it. We will have a more extensive discussion about this, but drawing an object in a canvas or a pad consists in "attaching" the object to that pad. When one uses object.Draw(), the object is NOT painted at this moment. It is only attached to the active pad or canvas.

Another method should be provided for the object to be painted, the Paint() method. This is all explained in the next paragraph.

As well as Draw() and Paint(), other methods may be provided by the designer of the class. When the mouse is moved or a button pressed/released, the TCanvas function named HandleInput() scans the list of objects in all it's pads and for each object calls some standard methods to make the object react to the event (mouse movement, click or whatever).

The second one is DistanceToPrimitive(px,py). This function computes a "distance" to an object from the mouse position at the pixel position (px,py, see definition at the end of this paragraph) and returns this distance in pixel units. The selected object will be the one with the shortest computed distance. To see how this works, select the "Event Status" item in the canvas "Options" menu. ROOT will display one status line showing the picked object. If the picked object is, for example, a histogram, the status line indicates the name of the histogram, the position x,y in histogram coordinates, the channel number and the channel content.

It's nice for the canvas to know what is the closest object from the mouse, but it's even nicer to be able to make this object react. The third standard method to be provided is ExecuteEvent(). This method actually does the event reaction.

Its prototype is where px and py are the coordinates at which the event occurred, except if the event is a key press, in which case px contains the key code.

```
void ExecuteEvent(Int_t event, Int_t px, Int_t py);
```

`Where event` is the event that occurs and is one of the following (defined in `Buttons.h`):

```
kNoEvent, kButton1Down, kButton2Down, kButton3Down,
kButton1Up, kButton2Up, kButton3Up, kButton1Motion,
kButton2Motion, kButton3Motion, kButton1Locate,
kButton2Locate, kButton3Locate, kButton1Double,
kButton2Double, kButton3Double, kKeyDown, kKeyUp,
kKeyPress, kMouseMotion, kMouseEnter, kMouseLeave.
```

We hope the names are self-explanatory.

Designing an `ExecuteEvent` method is not very easy, except if one wants very basic treatment. We will not go into that and let the reader refer to the sources of classes like `TLine` or `TBox`. Go and look at their `ExecuteEvent` method!

We can nevertheless give some reference to the various actions that may be performed. For example, one often wants to change the shape of the cursor when passing on top of an object. This is done with the `SetCursor` method:

```
gPad->SetCursor(cursor)
```

The argument `cursor` is the type of cursor. It may be:

```
kBottomLeft, kBottomRight, kTopLeft, kTopRight,
kBottomSide, kLeftSide, kTopSide, kRightSide, kMove,
kCross, kArrowHor, kArrowVer, kHand, kRotate, kPointer,
kArrowRight, kCaret, kWatch.
```

They are defined in `TVirtualX.h` and again we hope the names are self-explanatory. If not, try them by designing a small class. It may derive from something already known like `TLine`.

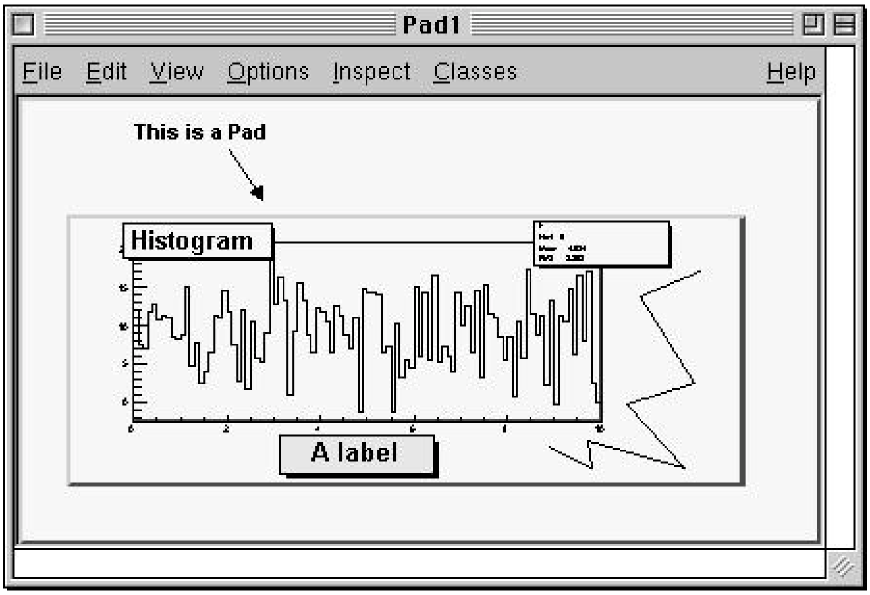
Note that the `ExecuteEvent()` functions may in turn; invoke such functions for other objects, in case an object is drawn using other objects. You can also exploit at best the virtues of inheritance. See for example how the class `TArrow` (derived from `TLine`) use or redefine the picking functions in its base class.

The last comment is that mouse position is always given in pixel units in all these standard functions. `px=0` and `py=0` corresponds to the top-left corner of the canvas. Here, we have followed the standard convention in windowing systems. Note that user coordinates in a canvas (pad) have the origin at the bottom-left corner of the canvas (pad). This is all explained in the paragraph "Coordinate system of a pad".

Graphical Containers: Canvas and Pad

We have talked a lot about canvases, which may be seen as windows. More generally, a graphical entity that contains graphical objects is called a Pad. A Canvas is a special kind of Pad. From now on, when we say something about pads, this also applies to canvases.

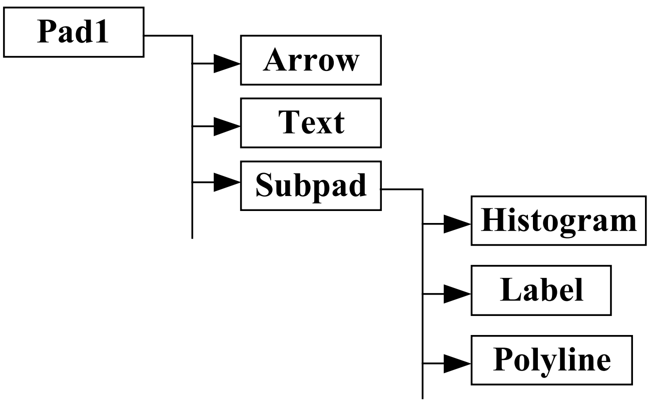
A pad (class `TPad`) is a graphical container in the sense it contains other graphical objects like histograms and arrows. It may contain other pads (sub-pads) as well. More technically, each pad has a linked list of pointers to the objects it holds.



Drawing an object is nothing more than adding its pointer to this list. Look for example at the code of `TH1::Draw()`. It is merely ten lines of code. The last statement is `AppendPad()`. This statement calls a method of `TObject` that just adds the pointer of the object, here a histogram, to the list of objects attached to the current pad. Since this is a `TObjects` method, every object may be "drawn", which means attached to a pad.

We can illustrate this by the following figure.

The image correspond to this structure:



When is the painting done then? The answer is: when needed. Every object that derives from `TObject` has a `Paint()` method. It may be empty, but for graphical objects, this routine contains all the instructions to effectively paint it in the active pad. Since a Pad has the list of objects it owns, it will call successively the `Paint()` method of each object, thus re-painting the whole pad on the screen. If the object is a sub-pad, its `Paint()` method will call the `Paint()` method of the objects attached, recursively calling `Paint()` for all the objects.

The Global Pad: `gPad`

When an object is drawn, it is always in the so-called active pad. For every day use, it is comfortable to be able to access the active pad, whatever it is. For that purpose, there is a global pointer, called ***`gPad`***. It is always pointing to the active pad. If you want to change the fill color of the active pad to blue but you don't know its name, do this.

```
root[] gPad->SetFillColor(38)
```

To get the list of colors, go to the paragraph "Color and color palettes" or if you have an opened canvas, click on the `View` menu, selecting the `Colors` item.

Finding an Object in a Pad

Now that we have a pointer to the active pad, ***`gPad`*** and that we know this pad contains some objects, it is sometimes interesting to access one of those objects. The method `GetPrimitive()` of `TPad`, i.e. `TPad::GetPrimitive(const char* name)` does exactly this. Since most of the objects that a pad contains derive from `TObject`, they have a name. The following statement will return a pointer to the object `myobjectname` and put that pointer into the variable `obj`. As you see, the type of returned pointer is (`TObject*`).

```
root[] obj = gPad->GetPrimitive("myobjectname")
(class TObject*)0x1063cba8
```

Even if your object is something more complicated, like a histogram `TH1F`, this is normal. A function cannot return more than one type. So the one chosen was the lowest common denominator to all possible classes, the class from which everything derives, `TObject`.

How do we get the right pointer then?

Simply do a cast of the function output that is transforming this output (pointer) into the right type. For example if the object is a `TPaveLabel`:

```
root[] obj = (TPaveLabel*)(gPad->GetPrimitive("myobjectname"))
(class TPaveLabel*)0x1063cba8
```

This works for all objects deriving from `TObject`. However, a question remains. An object has a name if it derives from `TNamed`, not from `TObject`. For example, an arrow (`TArrow`) doesn't have a name. In that case, the "name" is the name of the class. To know the name of an object, just click with the right button on it. The name appears at the top of the context menu.

In case of multiple unnamed objects, a call to `GetPrimitve("className")` returns the instance of the class that was first created. To retrieve a later instance you can use

`GetListOfPrimitives()`, which returns a list of all the objects on the pad,. From the list you can select the object you need.

Hiding an Object

Hiding an object in a pad can be made by removing it from the list of objects owned by that pad. This list is accessible by the `GetListOfPrimitives()` method of `TPad`. This method returns a pointer to a `TList`. Suppose we get the pointer to the object, we want to hide, call it `obj` (see paragraph above). We get the pointer to the list:

```
root[] li = gPad->GetListOfPrimitives()
```

Then remove the object from this list:

```
root[] li->Remove(obj)
```

The object will disappear from the pad as soon as the pad is updated (try to resize it for example).

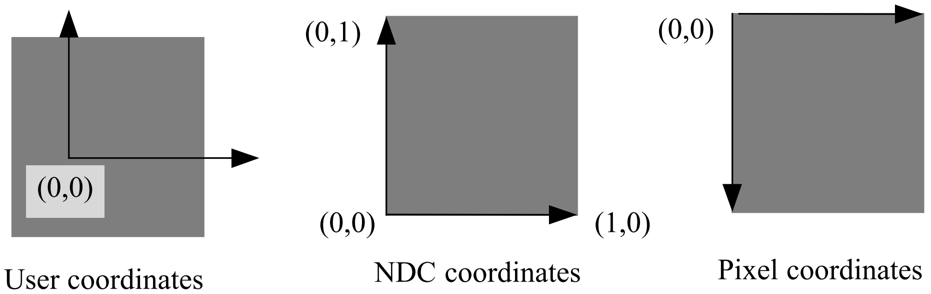
If one wants to make the object reappear:

```
root[] obj->Draw()
```

Caution, this will not work with composed objects, for example many histograms drawn on the same plot (with the option "same"). There are other ways! Try to use the method described here for simple objects.

The Coordinate Systems of a Pad

Three coordinate systems may be used in a TPad: pixel coordinates, normalized coordinates (NDC), and user coordinates.



The User Coordinate System

The most common is the user coordinate system. Most methods of TPad use the user coordinates, and all graphic primitives have their parameters defined in terms of user coordinates. By default, when an empty pad is drawn, the user coordinates are set to a range from 0 to 1 starting at the lower left corner. At this point they are equivalent of the NDC coordinates (see below). If you draw a high level graphical object, such as a histogram or a function, the user coordinates are set to the coordinates of the histogram. Therefore, when you set a point it will be in the histogram coordinates

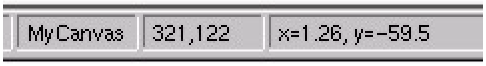
For a newly created blank pad, one may use `TPad::Range` to set the user coordinate system. This function is defined as:

```
void Range(float x1, float y1, float x2, float y2)
```

The arguments `x1, x2` defines the new range in the x direction, and the `y1, y2` define the new range in the y-direction.

```
root[] TCanvas MyCanvas ("MyCanvas")
root[] gPad->Range(-100, -100, 100, 100)
```

This will set the active pad to have both coordinates to go from -100 to 100, with the center of the pad at (0,0). You can visually check the coordinates by viewing the status bar in the canvas. To display the status bar select Options:Event Status in the canvas menu.



The Normalized Coordinate System (NDC)

Normalized coordinates are independent of the window size and of the user system. The coordinates range from 0 to 1 and (0,0) correspond to the bottom-left corner of the pad. Several internal ROOT functions use the NDC system (3D primitives, PostScript, log scale mapping to linear scale). You may want to use this system if the user coordinates are not known ahead of time.

The Pixel Coordinate System

The least common is the pixel coordinate system, used by functions such as `DistanceToPrimitive()` and `ExecuteEvent()`. Its primary use is for cursor position, which is always given in pixel coordinates. If (`px,py`) is the cursor position, `px=0` and `py=0` corresponds to the top-left corner of the pad, which is the standard convention in windowing systems.

Using NDC for a particular Object

Most of the time, you will be using the user coordinate system. But sometimes, you will want to use NDC. For example, if you want to draw text always at the same place over a histogram, no matter what the histogram coordinates are. There are two ways to do this. You can set the NDC for one object or may convert NDC to user coordinates. Most graphical objects offer an option to be drawn in NDC. For instance, a line (`TLine`) may be drawn in NDC by using `DrawLineNDC()`. A latex formula or a text may use `TText::SetNDC()` to be drawn in NDC coordinates.

Converting between Coordinates Systems

There are a few utility functions in `TPad` to convert from one system of coordinates to another. In the following table, a point is defined by `(px,py)` in pixel coordinates; `(ux,uy)` in user coordinates, `(ndcx,ndcy)` in NDC coordinates.

Conversion	**Methods of `TPad`**	**Returns**

`Pixel to User`	`PixeltoX(px)`
	`PixeltoY(py)`
	`PixeltoXY(px,py, &ux, &uy)`
		`double`
		`double`
		`changes ux,uy`

`NDC to Pixel`	`UtoPixel(ndcx)` `VtoPixel(ndcy)`	`int` `int`

`User to Pixel`	`XtoPixel(ux)`
	`YtoPixel(uy)`
	`XYtoPixel(ux,uy,&px,&py)`
		`int`
		`int`
		`changes px,py`

Dividing a Pad into Sub-pads

Dividing a pad into sub pads in order for instance to draw a few histograms, may be done in two ways. The first is to build pad objects and to draw them into a parent pad, which may be a canvas. The second is to automatically divide a pad into horizontal and vertical sub pads.

Creating a Single Sub-pad

The simplest way to divide a pad is to build sub-pads in it. However, this forces the user to explicitly indicate the size and position of those sub-pads. Suppose we want to build a sub-pad in the active pad (pointed by ***`gPad`***). First, we build it, using a `TPad` constructor:

```
root[] subpad1 = new TPad("subpad1","The first
subpad",.1,.1,.5,.5)
```

One gives the coordinates of the lower left point (0.1,0.1) and of the upper right one (0.5,0.5). These coordinates are in NDC. This means that they are independent of the user coordinates system, in particular if you have already drawn for example a histogram in the mother pad.

The only thing left is to draw the pad:

```
root[] subpad1->Draw()
```

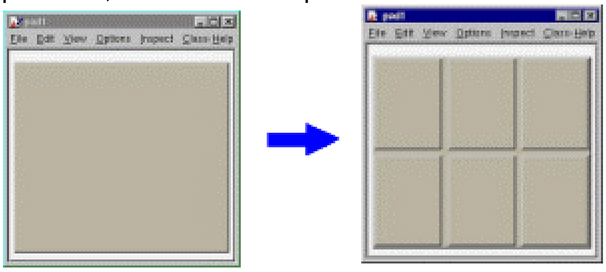
If you want more sub-pads, you have to repeat this procedure as many times as necessary.

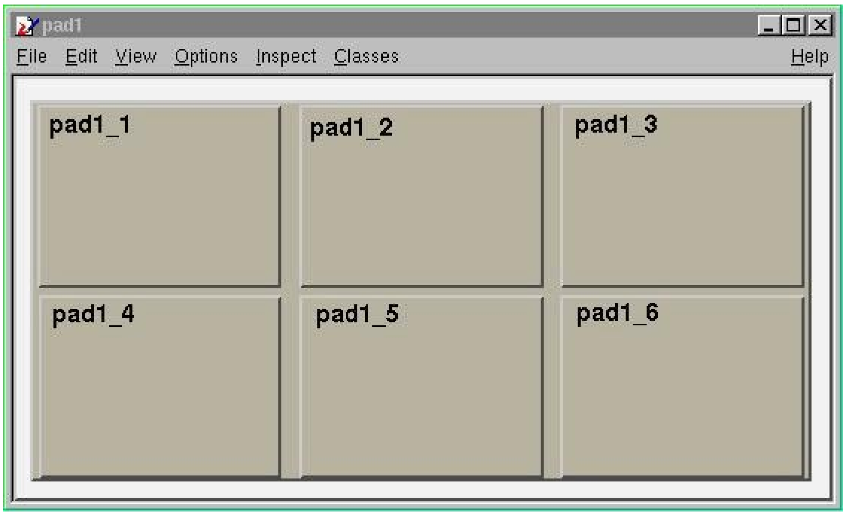
Dividing a Canvas into Sub-Pads

The manual way of dividing a pad into sub-pads is sometimes very tedious. There is a way to automatically generate horizontal and vertical sub-pads inside a given pad.

```
root[] pad1->Divide(3,2)
```

If `pad1` is a pad then, it will divide the pad into 3 columns of 2 sub-pads:





The generated sub-pads get names `pad1_i` where `i` is `1` to `nxm`. In our case `pad1_1`, `pad1_2`... `pad1_6`:

The names `pad1_1` etc… correspond to new variables in CINT, so you may use them as soon as the `pad->Divide()` was executed. However, in a compiled program, one has to access these objects. Remember that a pad contains other objects and that these objects may, themselves be pads. So we can use the `GetPrimitive()` method of `TPad`:

```
TPad* pad1_1 = (TPad*)(pad1->GetPrimitive("pad1_1"))
```

One question remains. In case one does an automatic divide, how can one set the default margins between pads? This is done by adding two parameters to `Divide()`, which are the margins in `x` and `y`:

```
root[] pad1->Divide(3,2,0.1,0.1)
```

The margins are here set to 10% of the parent pad width.

Updating the Pad

For performance reasons, a pad is not updated with every change. For example, changing the coordinates of the pad does not automatically redraw it. Instead, the pad has a "bit-modified" that triggers a redraw. This bit is automatically set by:

1. Touching the pad with the mouse. For example resizing it with the mouse.
2. Finishing the execution of a script.
3. Adding a new primitive or modifying some primitives for example the name and title of an object.

You can also set the "bit-modified" explicitly with the `Modified` method:

```
// this pad has changed
root[] pad1->Modified()
// recursively update all modified pads:
root[] c1->Update()
```

A subsequent call to `TCanvas->Update()` scans the list of sub-pads and repaints the pads declared modified.

In compiled code or in a long macro, you may want to access an object created during the paint process. To do so you can force the painting with a `TCanvas::Update()`. For example a `TGraph` creates a histogram (`TH1`) to paint itself. In this case the internal histogram obtained with `TGraph::GetHistogram()` is created only after the pad is painted. The pad is painted automatically after the script is finished executing or if you force the painting with `TPad::Modified` followed by a `TCanvas::Update`.

Note that it is not necessary to call `TPad::Modified` after a call to `Draw()`. The "bit-modified" is set automatically by `Draw()`.

A note about the "bit-modified" in sub pads: when you want to update a sub pad in your canvas, you need to call `pad->Modified` rather than `canvas->Modified`, and follow it with a `canvas->Update`. If you use `canvas->Modified`, followed by a call to `canvas->Update`, the sub pad has not been declared modified and it will not be updated.

Also note that a call to `pad->Update` where pad is a sub pad of canvas, calls canvas->Update and recursively updates all the pads on the canvas.

Making a Pad Transparent

As we will see in the paragraph "Fill attributes", a fill style (type of hatching) may be set for a pad.

```
root[] pad1->SetFillStyle(istyle)
```

This is done with the `SetFillStyle` method where `istyle` is a style number, defined in "Fill attributes".

A special set of styles allows handling of various levels of transparency. These are styles number 4000 to 4100, 4000 being fully transparent and 4100 fully opaque.

So, suppose you have an existing canvas with several pads. You create a new pad (transparent) covering for example the entire canvas. Then you draw your primitives in this pad.

The same can be achieved with the graphics editor.

For example:

```
root [] .x tutorials/h1draw.C
root [] TPad *newpad=new TPad("newpad","a transparent
pad,0,0,1,1);
root [] newpad.SetFillStyle(4000);
root [] newpad.Draw();
root [] newpad.cd();
root [] // create some primitives, etc
```

Setting the Log Scale is a Pad Attribute

Setting the scale to logarithmic or linear is an attribute of the pad, not the axis or the histogram. The scale is an attribute of the pad because you may want to draw the same histogram in linear scale in one pad and in log scale in another pad. Frequently, we see several histograms on top of each other in the same pad. It would be very inconvenient to set the scale attribute for each histogram in a pad. Furthermore, if the logic were in the histogram class (or each object), one would have to test for the scale setting in each the `Paint` methods of all objects.

If you have a pad with a histogram, a right-click on the pad, outside of the histograms frame will convince you. The `SetLogx()`, `SetLogy()` and `SetLogz()` methods are there. As you see, `TPad` defines log scale for the two directions `x` and `y` plus `z` if you want to draw a 3D representation of some function or histogram.

The way to set log scale in the `x` direction for the active pad is:

```
root [] gPad->SetLogx(1)
```

To reset log in the `z` direction:

```
root [] gPad->SetLogz(0)
```

If you have a divided pad, you need to set the scale on each of the sub-pads. Setting it on the containing pad does not automatically propagate to the sub-pads. Here is an example of how to set the log scale for the x-axis on a canvas with four sub-pads:

```
root [] TCanvas MyCanvas("MyCanvas", "My Canvas")
root [] MyCanvas->Divide(2,2)
root [] MyCanvas->cd(1)
root [] gPad->SetLogx()
root [] MyCanvas->cd(2)
root [] gPad->SetLogx()
root [] MyCanvas->cd(3)
root [] gPad->SetLogx()
```

Graphical Objects

In this paragraph, we describe the various simple 2D graphical objects defined in ROOT. Usually, one defines these objects with their constructor and draws them with their `Draw()` method. Therefore, the examples will be very brief. Most graphical objects have line and fill attributes (color, width) that will be described in “Graphical objects attributes”.

If the user wants more information, the class names are given and he may refer to the online developer documentation. This is especially true for functions and methods that set and get internal values of the objects described here.

By default 2D graphical objects are created in User Coordinates with 0,0 in the lower left corner.

Lines, Arrows, and Geometrical Objects

Line: Class TLine

The simplest graphical object is a line. It is implemented in the `TLine` class. The constructor is:

```
TLine(Double_t x1, Double_t y1, Double_t x2, Double_t y2)
```

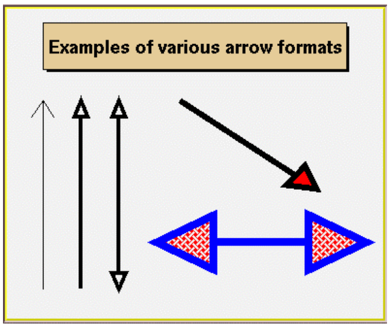
The arguments `x1, y1, x2, y2` are the coordinates of the first and second point.

This constructor may be used as in:

```
root [] l = new TLine(0.2,0.2,0.8,0.3)
root [] l->Draw()
```

Arrows: Class TArrow

Different arrow formats as show in the picture below are available.



Once an arrow is drawn on the screen, one can:

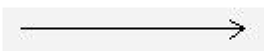
- click on one of the edges and move this edge.
- click on any other arrow part to move the entire arrow.

The constructor is:

```
TArrow(Double_t x1, Double_t y1,Double_t x2, Double_t y2,
Float_t arrowsize, Option_t *option)
```

It defines an arrow between points `x1,y1` and `x2,y2`. The arrow size is in percentage of the pad height.

The options are the following:

option = ">" 

option = "<" 

option = "|>" 

option = "<|" 

option = "<>" 

option = "<|>" 

If the fill colordefined if `FillColor == 0`, draw open triangle else draw full triangle with fill color. If `ar` is an arrow object, fill color is set with:

```
ar.SetFillColor(icolor);
```

Where `icolor` is the color defined in “Color and color palettes”.

The opening angle between the two sides of the arrow is 60 degrees. It can be changed with `ar->SetAngle(angle)`, where angle is expressed in degrees.

Poly-line: Class `TPolyLine`

A poly-line is a set of joint segments. It is defined by a set of N points in a 2D space. Its constructor is:

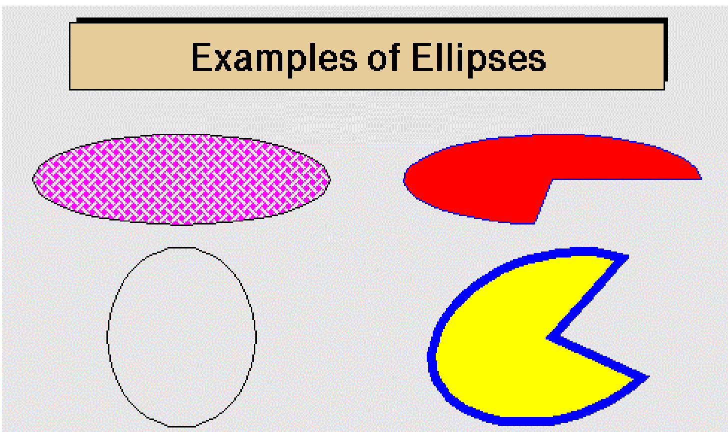
```
TPolyLine(Int_t n, Double_t* x, Double_t* y, Option_t*
option)
```

Where `n` is the number of points, and `x` and `y` are arrays of `n` elements with the coordinates of the points.

`TPolyLine` can be used by it self, but is also a base class for other objects, such as curly arcs.

Circles, Ellipses: Class `TEllipse`

Ellipse is a general ellipse that can be truncated and rotated. An ellipse is defined by its center `(x1,y1)` and two radii `r1` and `r2`. A minimum and maximum angle may be specified (`phimin, phimax`). The picture below illustrates different types of ellipses:



The Ellipse may be rotated with an angle theta.

The attributes of the outline line and of the fill area are described in "Graphical objects attributes"

The constructor of a `TEllipse` object is:

```
TEllipse(Double_t x1, Double_t y1,Double_t r1,Double_t
r2,Double_t phimin, Double_t phimax, Double_t theta)
```

An ellipse may be created with a statement like:

```
root [] e = new TEllipse(0.2,0.2,0.8,0.3)
root [] e->Draw()
```

Rectangles: Classes TBox and TWbox

A rectangle is defined by the class `TBox` since it is a base class for many different higher-level graphical primitives.

A box is defined by its bottom left coordinates `x1, y1` and its top right coordinates `x2, y2`.

The constructor being:

```
TBox(Double_t x1, Double_t y1, Double_t x2, Double_t y2)
```

It may be used as in:

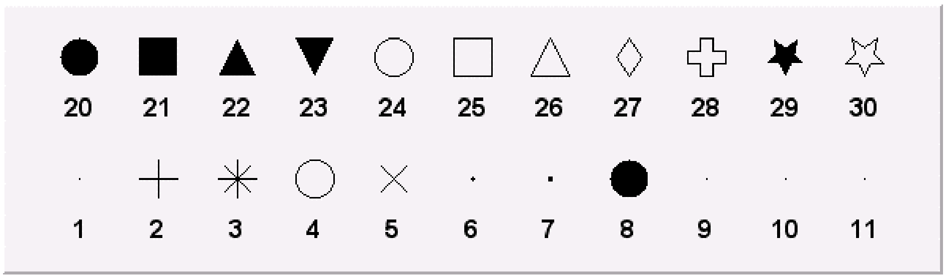
```
root [] b = new TBox(0.2,0.2,0.8,0.3)
root [] b->Draw()
```

A `TWbox` is a rectangle (`TBox`) with a border size and a border mode:

The attributes of the outline line and of the fill area are described in "Graphical Objects Attributes"

One Point, or Marker: Class `TMarker`

A marker is a point with a fancy shape! The possible markers are the following:

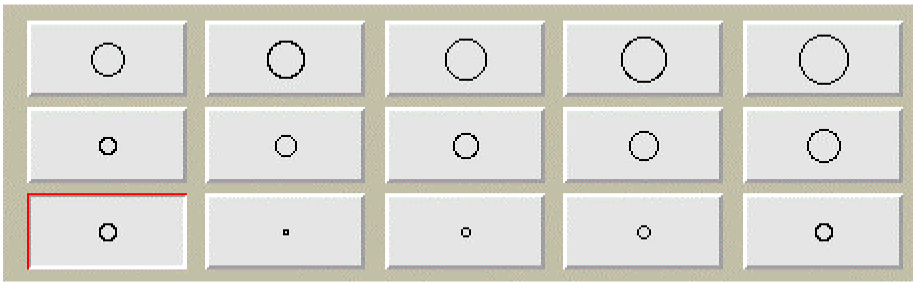


One marker is build via the constructor:

```
TMarker(Double_t x, Double_t y, Int_t marker)
```

The parameters `x` and `y` are the coordinates of the marker and `marker` is the type, shown above.

Suppose `ma` is a valid marker. One can set the size of the marker with `ma->SetMarkerSize(size)`, where `size` is the desired size. The available sizes are:



Sizes smaller than 1 may be specified.

Set of Points: Class `TPolyMarker`

A `TPolyMaker` is defined by an array on N points in a 2-D space. At each point `x[i], y[i]` a marker is drawn. The list of marker types is shown in the previous paragraph.

The marker attributes are managed by the class `TAttMarker` and are described in "Graphical objects attributes"

The constructor for a `TPolyMarker` is:

```
TPolyMarker(Int_t n, Double_t *x, Double_t *y, Option_t
*option)
```

Where `x` and `y` are arrays of coordinates for the `n` points that form the poly-marker.

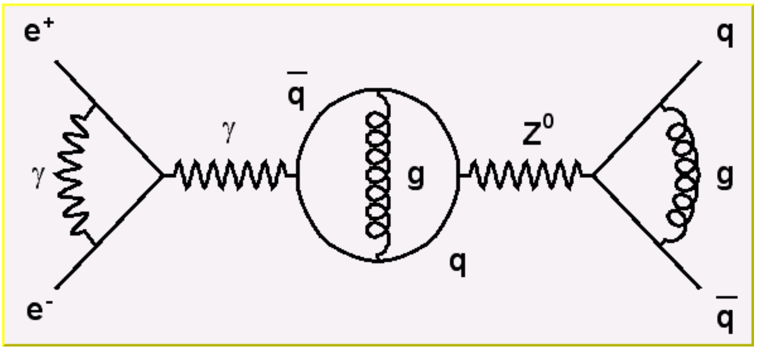
Curly and Wavy Lines for Feynman Diagrams

This is a peculiarity of particle physics, but we do need sometimes to draw Feynman diagrams. Our friends working in banking can skip this part.

A set of classes implements curly or wavy poly-lines typically used to draw Feynman diagrams. Amplitudes and wavelengths may be specified in the constructors, via commands or interactively from context menus. These classes are `TCurlyLine` and `TCurlyArc`.

These classes make use of `TPolyLine` by inheritance; `ExecuteEvent` methods are highly inspired from the methods used in `TPolyLine` and `TArc`.

The picture below has been generated by the tutorial `feynman.C`:



The constructors are:

```
TCurlyLine(Double_t x1, Double_t y1, Double_t x2, Double_t
y2, Double_t wavelength, Double_t amplitude)
```

With the starting point `(x1, y1)`, end point `(x2, y2)`. The wavelength and amplitude are given in percent of the pad height

For `TCurlyArc`, the constructor is:

```
TCurlyArc(Double_t x1, Double_t y1, Double_t rad, Double_t
phimin, Double_t phimax, Double_t wavelength, Double_t
amplitude)
```

The center is `(x1, y1)` and the radius `rad`. The wavelength and amplitude are given in percent of the line length, `phimin` and `phimax`, which are the starting and ending angle of the arc, are given in degrees.

Refer to `$ROOTSYS/tutorials/feynman.C` for the script that built the picture above.

Text and Latex Mathematical Expressions

Text displayed in a pad may be embedded into boxes, called paves (such as `PaveLabels`), or titles of graphs or many other objects but it can live a life of its own. All text displayed in ROOT graphics is an object of class `TText`. For a physicist, it will be most of the time a `TLatex` expression (which derives from `TText`).

`TLatex` has been conceived to draw mathematical formulae or equations. Its syntax is very similar to the Latex one in mathematical mode.

Subscripts and Superscripts

Subscripts and superscripts are made with the _ and ^ commands. These commands can be combined to make complicated subscript and superscript expressions. You may choose how to display subscripts and superscripts using the 2 functions `SetIndiceSize(Double_t)` and `SetLimitIndiceSize(Int_t)`.

Examples of what can be obtained using subscripts and superscripts:

The expression	Gives	The expression	Gives	The expression	Gives
`x^{2y}`	x^{2y}	`x^{y^{2}}`	$x^{y^{2}}$	`x^{y}_{1}`	x_1^y
`x_{2y}`	x_{2y}	`x^{y_{1}}`	x^{y_1}	`x_{1}^{y}`	x_1^y

Fractions

Fractions denoted by the `/` symbol are made in the obvious way. The `#frac` command is used for large fractions in displayed formula; it has two arguments: the numerator and the denominator. For example, this equation is obtained by following expression.

$$x = \frac{y + z/2}{y^2 + 1}$$

`x=#frac{y+z/2}{y^{2}+1}`

Roots

The `#sqrt` command produces the square ROOT of its argument; it has an optional first argument for other roots.

Example: `#sqrt{10}` `#sqrt[3]{10}` $\sqrt{10}$ $\sqrt[3]{10}$

Mathematical Symbols

`TLatex` can make mathematical and other symbols. A few of them, such as + and >, are produced by typing the corresponding keyboard character. Others are obtained with the commands in the following table.

≤	**#leq**	/	**#/**	∞	**#infty**	〉	**#GT**
♣	**#club**	♦	**#diamond**	♥	**#heart**	♠	**#spade**
↔	**#leftrightarrow**	←	**#leftarrow**	↑	**#uparrow**	→	**#rightarrow**
↓	**#downarrow**	°	**#circ**	±	**#pm**	"	**#doublequote**
≥	**#geq**	×	**#times**	∝	**#propto**	∂	**#partial**
•	**#bullet**	÷	**#divide**	≠	**#neq**	≡	**#equiv**
≈	**#approx**	…	**#3dots**	∣	**#cbar**	—	**#topbar**
↵	**#downleftarrow**	ℵ	**#aleph**	ℑ	**#Jgothic**	ℜ	**#Rgothic**
⊙	**#odot**	⊗	**#otimes**	⊕	**#oplus**	∅	**#oslash**
∩	**#cap**	∪	**#cup**	⊃	**#supset**	⊇	**#supseteq**
⊄	**#notsubset**	⊂	**#subset**	⊆	**#subseteq**	∈	**#in**
∉	**#notin**	∠	**#angle**	∇	**#nabla**	®	**#oright**
©	**#ocopyright**	™	**#trademark**	∏	**#prod**	√	**#surd**
·	**#upoint**	¬	**#corner**	∧	**#wedge**	∨	**#vee**
⇔	**#Leftrightarrow**	⇐	**#Leftarrow**	⇑	**#Uparrow**	⇒	**#Rightarrow**
⇓	**#Downarrow**	♦	**#diamond**	〈	**#LT**	□	**#Box**
©	**#copyright**	™	**#void3**	∑	**#sum**	℘	**#voidn**
∣	**#lbar**	⎝	**#arcbottom**	—	**#topbar**	⎛	**#arctop**
⎣	**#bottombar**	⎛	**#arcbar**	{	**#ltbar**	∫	**#int**
‖	**#parallel**	⊥	**#perp**	〉	**#GT**	ƒ	**#voidb**

Delimiters

You can produce three kinds of proportional delimiters.

`#[]{....}` or "a la" Latex `#left[.....#right]` : big square brackets

`#{}{....}` or `#left{.....#right}`: big curly brackets

`#||{....}` or `#left|.....#right|`: big absolute value symbol

`#(){....}` or `#left(.....#right)`: big parenthesis

Greek Letters

The command to produce a lowercase Greek letter is obtained by adding a `#` to the name of the letter. For an uppercase Greek letter, just capitalize the first letter of the command name.

```
#alpha #beta #gamma #delta #epsilon #zeta #eta #theta #iota
#kappa #lambda #mu #nu #xi #omicron #pi #varpi #rho #sigma
#tau #upsilon #phi #varphi #chi #psi #omega #Gamma #Delta
#Theta #Lambda #Xi #Pi #Sigma #Upsilon #Phi #Psi #Omega
```

Accents, Arrows and Bars

Symbols in a formula are sometimes placed one above another. `TLatex` provides special commands for doing this.

`#hat{a}` = hat

`#check` = inverted hat

`#acute` = acute

`#grave` = accent grave

`#dot` = derivative

`#ddot` = double derivative

$\bar{a}$ Is obtained with `#bar{a}`

$\vec{a}$ Is obtained with `#vec{a}`

Changing Style in Math Mode

You can change the font and the text color at any moment using:

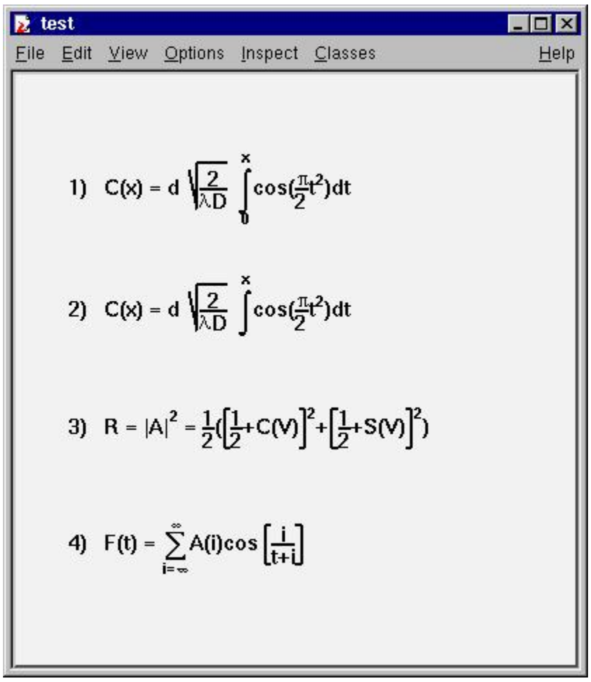
`#font[font-number]{...} and #color[color-number]{...}`

Example 1

The following script (`$ROOTSYS/tutorials/latex.C`)

```
{
 gROOT->Reset();
 TCanvas c1("c1","Latex",600,700);
 TLatex l;
 l.SetTextAlign(12);
 l.SetTextSize(0.04);
 l.DrawLatex(0.1,0.8,"1) C(x) = d #sqrt{#frac{2}{#lambdaD}}
                   #int^{x}_{0}cos(#frac{#pi}{2}t^{2})dt");
 l.DrawLatex(0.1,0.6,"2) C(x) = d #sqrt{#frac{2}{#lambdaD}}
                   #int^{x}cos(#frac{#pi}{2}t^{2})dt");
 l.DrawLatex(0.1,0.4,"3)   R = |A|^{2} =
                   #frac{1}{2}(#[]{#frac{1}{2}+C(V)}^{2}+
                   #[]{#frac{1}{2}+S(V)}^{2})");
 l.DrawLatex(0.1,0.2,"4)   F(t) = #sum_{i=
              -#infty}^{#infty}A(i)cos#[]{#frac{i}{t+i}}");
}
```

The script makes this picture:

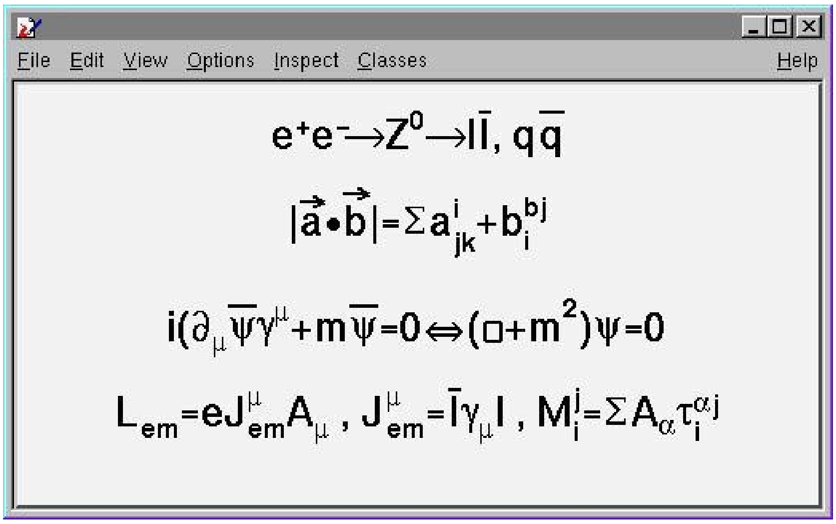


Example 2

The following script (`$ROOTSYS/tutorials/latex2.C`):

```
{
 gROOT->Reset();
 TCanvas c1("c1","Latex",600,700);
 TLatex l;
 l.SetTextAlign(23);
 l.SetTextSize(0.1);
 l.DrawLatex(0.5,0.95,"e^{+}e^{-}#rightarrowZ^{0}
                      #rightarrowI#bar{I}, q#bar{q}");
 l.DrawLatex(0.5,0.75,"|#vec{a}#bullet#vec{b}|=
                      #Sigmaa^{i}_{jk}+b^{bj}_{i}");
 l.DrawLatex(0.5,0.5,"i(#partial_{#mu}#bar{#psi}#gamma^{#mu}
                        +m#bar{#psi}=0
                        #Leftrightarrow(#Box+m^{2})#psi=0");
 l.DrawLatex(0.5,0.3,"L_{em}=eJ^{#mu}_{em}A_{#mu} ,
                      J^{#mu}_{em}=#bar{I}#gamma_{#mu}I
           M^{j}_{i}=#SigmaA_{#alpha}#tau^{#alphaj}_{i}");
}
```

The result is the following picture:

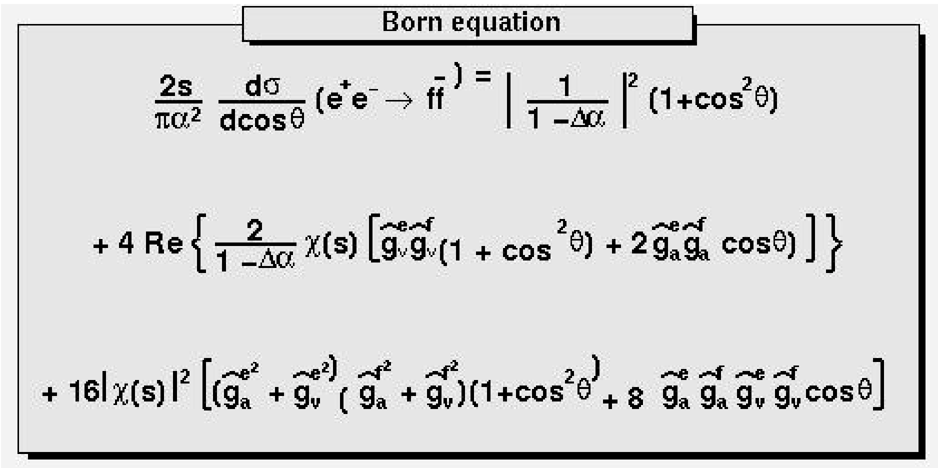


Example 3

The following script (`$ROOTSYS/tutorials/latex3.C`):

```
{
 gROOT->Reset();
 TCanvas c1("c1");
 TPaveText pt(.1,.5,.9,.9);
 pt.AddText("#frac{2s}{#pi#alpha^{2}}
             #frac{d#sigma}{dcos#theta} (e^{+}e^{-}
             #rightarrow f#bar{f} ) = ");
 pt.AddText("#left| #frac{1}{1 - #Delta#alpha} #right|^{2}
             (1+cos^{2}#theta");
 pt.AddText("+ 4 Re #left{ #frac{2}{1 - #Delta#alpha} #chi(s)
             #[]{#hat{g}_{#nu}^{e}#hat{g}_{#nu}^{f}
             (1 + cos^{2}#theta) + 2 #hat{g}_{a}^{e}
             #hat{g}_{a}^{f} cos#theta) } #right}");
 pt.SetLabel("Born equation");
 pt.Draw();
}
```

The result is the following picture:



Text in Labels and TPaves

Text displayed in a pad may be embedded into boxes, called paves, or may be drawn alone. In any case, it is recommended to use a Latex expression, which is covered in the previous paragraph. Using `TLatex` is valid whether the text is embedded or not. In fact, you will use Latex expressions without knowing it since it is the standard for all the embedded text.

A pave is just a box with a border size and a shadow option. The options common to all types of paves and used when building those objects, are the following:

Option = "`T`" Top frame

Option = "`B`" Bottom frame

Option = "`R`" Right frame

Option = "`L`" Left frame

Option = "`NDC`" `x1,y1,x2,y2` are given in NDC

Option = "`ARC`" corners are rounded

We will see the practical use of these options in the description of the more functional objects like `TPaveLabels`.

There are several categories of paves containing text:

TPaveLabels

`TPaveLabels` are panels containing one line of text. They are used for labeling. The constructor is:

```
TPaveLabel(Double_t x1, Double_t y1,Double_t x2, Double_t
y2, const char *label, Option_t *option)
```

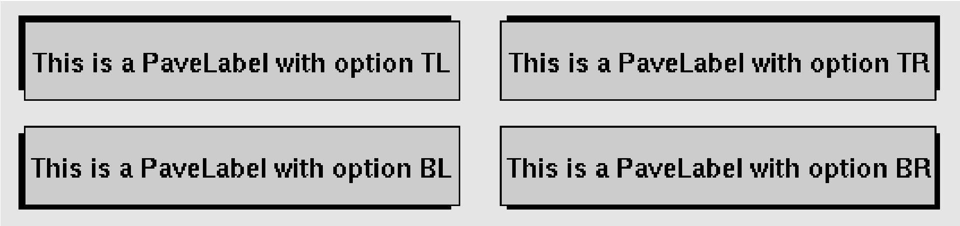
Where `(x1, y1)` are the coordinates of the bottom left corner, `(x2, y2)` the coordinates of the upper right corner. “`label`” is the text to be displayed and “`option`” is the drawing option, described above. By default, the border size is 5 and the option is “`br`”.

If one wants to set the border size to some other value, one may use the `SetBorderSize()` method. For example, suppose we have a histogram, which limits are `(-100, 100)` in the `x` direction and `(0,1000)` in the y direction.

The following lines will draw a label in the center of the histogram, with no border. If one wants the label position to be independent of the histogram coordinates, or user coordinates, one can use the option “`NDC`”. See the paragraph about coordinate systems for more information.

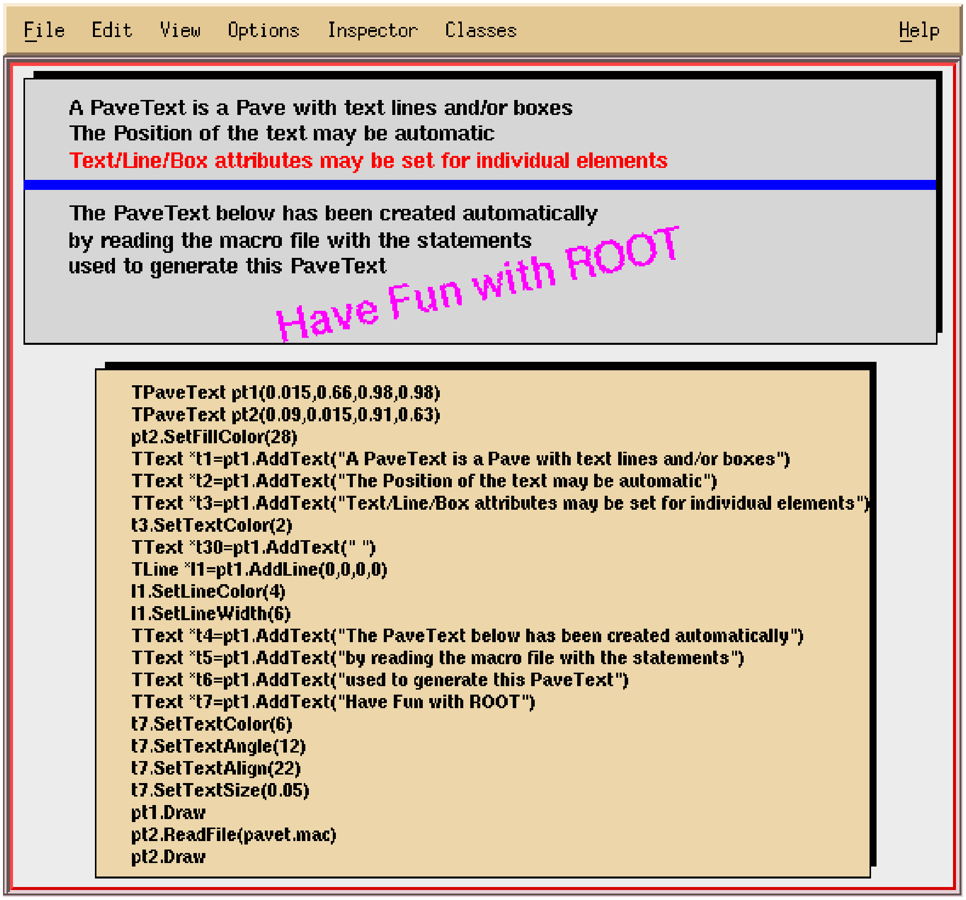
```
root[] pl = new TPaveLabel(-50, 0, 50,200,”Some text”)
root[] pl->SetBorderSize(0)
root[] pl->Draw()
```

Here are examples of what may be obtained:



TPaveText

A `TPaveLabel` can contain only one line of text. A `TPaveText` may contain several lines. This is the only difference. This picture illustrates and explains some of the points of `TPaveText`. Once a `TPaveText` is drawn, a line can be added or removed by brining up the context menu with the mouse.

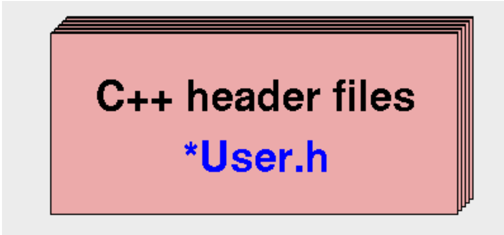


TPavesText

A `TPavesText` is a stack of text panels (see `TPaveText`). One can set the number of stacked panels at building time. The constructor is:

```
TPavesText(Double_t x1, Double_t y1, Double_t x2, Double_t
y2, Int_t npaves, Option_t* option)
```

By default, the number of stacked panels is 5 and option = "`br`"



Sliders

Sliders may be used for showing the evolution of a process or setting the limits of an object's value interactively. A `TSlider` object contains a slider box that can be moved or resized.

Slider drawing options include the possibility to change the slider starting and ending positions or only one of them.

The current slider position can be retrieved via the functions `TSlider::GetMinimum()` and `TSlider::GetMaximum()`. These two functions return numbers in the range `[0,1]`.

One may set a C expression to be executed when the mouse button 1 is released. This is done with the `TSlider::SetMethod()` function.

It is also possible to reference an object. If no method or C expression has been set, and an object is referenced (`SetObject` has been called), while the slider is being moved/resized, the object `ExecuteEvent` function is called.

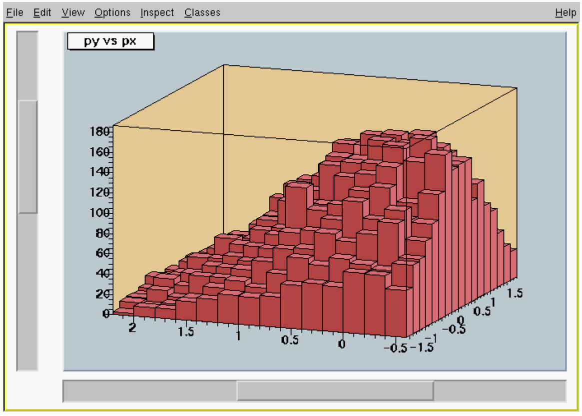
Let's see an example using SetMethod. The script is called xyslider.C. You can find this script in $ROOTSYS/tutorials.

```
{
   // Example of script featuring two sliders
   TFile *f = new TFile("hsimple.root");
   TH2F *hpxpy = (TH2F*)f->Get("hpxpy");
   TCanvas *c1 = new TCanvas("c1");
   TPad *pad = new TPad("pad","lego pad",
                   0.1,0.1,0.98,0.98);
   pad->SetFillColor(33);
   pad->Draw();
   pad->cd();
   gStyle->SetFrameFillColor(42);
   hpxpy->SetFillColor(46);
   hpxpy->Draw("lego1");
   c1->cd();

  // Create two sliders in main canvas. When button1
  // of the mouse will be released, action.C will be called
   TSlider *xslider = new TSlider
                    ("xslider","x",.1,.02,.98,.08);
   xslider->SetMethod(".x action.C");
   TSlider *yslider = new TSlider
                    ("yslider","y",.02,.1,.06,.98);
   yslider->SetMethod(".x action.C");
}
```

The script that is executed when button 1 is released is the following (script action.C):

```
{
   Int_t nx = hpxpy->GetXaxis()->GetNbins();
   Int_t ny = hpxpy->GetYaxis()->GetNbins();
   Int_t binxmin = nx*xslider->GetMinimum();
   Int_t binxmax = nx*xslider->GetMaximum();
   hpxpy->GetXaxis()->SetRange(binxmin,binxmax);
   Int_t binymin = ny*yslider->GetMinimum();
   Int_t binymax = ny*yslider->GetMaximum();
   hpxpy->GetYaxis()->SetRange(binymin,binymax);
   pad->cd();
   hpxpy->Draw("lego1");
   c1->Update();
}
```

The canvas and the sliders created in the above script are shown in the picture below.



The second example uses `SetObject` (script `xyslider.C`). Same example as above but using the `SetMethod`:

```
Myclass *obj = new Myclass();
// Myclass derived from TObject
xslider->SetObject(obj);
 yslider->SetObject(obj);
```

When one of the sliders will be changed, `Myclass::ExecuteEvent()` will be called with `px=0` and `py = 0`.

Axis

The axis objects are automatically built by various high level objects such as histograms or graphs. Once build, one may access them and change their characteristics. It is also possible, for some particular purposes to build axis on their own. This may be useful for example in the case one wants to draw two axis for the same plot, one on the left and one on the right.

For historical reasons, there are two classes representing axis.

`TAxis` is the axis object, which will be returned when calling the `TH1::GetAxis()` method.

```
TAxis *axis = histo->GetXaxis()
```

Of course, you may do the same for `Y` and `Z`-axis.

The graphical representation of an axis is done with the `TGaxis` class. Instances of this class are generated by the histogram classes and `TGraph`. This is internal and the user should not have to see it.

Axis Options and Characteristics

The axis options are most simply set with the styles. The available style options controlling specific axis options are the following:

```
SetAxisColor(Color_t color = 1, Option_t* axis = X)
SetLabelColor(Color_t color = 1, Option_t* axis = X)
SetLabelFont(Style_t font = 62, Option_t* axis = X)
SetLabelOffset(Float_t offset = 0.005, Option_t* axis = X)
SetLabelSize(Float_t size = 0.04, Option_t* axis = X)
SetNdivisions(Int_t n = 510, Option_t* axis = X)
SetTickLength(Float_t length = 0.03, Option_t* axis = X)
SetTitleOffset(Float_t offset = 1, Option_t* axis = X)
SetTitleSize(Float_t size = 0.02, Option_t* axis = X)
```

As one can see, the default is always for `X`-axis. As an example, if one wants the label size of all subsequent `Y`-axis to be 0.07, one may do:

```
gStyle->SetLabelSize(0.07,"Y");
```

Of course, getters corresponding to the described setters are available. Furthermore, the general options, not specific to axis, as for instance `SetTitleTextColor()` are valid and do have an effect on axis characteristics

Axis Title

The axis title is set, as with all named objects, by

```
axis->SetTitle("Whatever title you want");
```

When the axis is embedded into a histogram or a graph, one has to first extract the axis object:

```
h->GetXaxis()->SetTitle("Whatever title you want")
```

Drawing Axis independently of Graphs or Histograms

An axis may be drawn independently of a histogram or a graph. This may be useful to draw for example a supplementary axis for a graph. In this case, one has to use the `TGaxis` class, the graphical representation of an axis. One may use the standard constructor for this kind of objects:

```
TGaxis(Double_t xmin, Double_t ymin, Double_t xmax,
Double_t ymax, Double_t wmin, Double_t wmax, Int_t ndiv =
510, Option_t* chopt, Double_t gridlength = 0)
```

The arguments `xmin, ymin` are the coordinates of the axis' start in the user coordinates system, `and xmax, ymax` are the end coordinates. The arguments `wmin` and `wmax` are the minimum (at the start) and maximum (at the end) values to be represented on the axis.

`ndiv` is the number of divisions and should be set to:

`ndiv = N1 + 100*N2 + 10000*N3`

`N1` = number of first divisions.

`N2` = number of secondary divisions.

`N3` = number of tertiary divisions.

For example:

`ndiv` = 0: no tick marks.

`ndiv` = 2: 2 divisions, one tick mark in the middle of the axis.

The options, given by the "`chopt`" string are the following:

- `chopt = 'G'`: logarithmic scale, default is linear.
- `chopt = 'B'`: Blank axis. Useful to superpose the axis.

Instead of the `wmin,wmax` arguments of the normal constructor, i.e. the limits of the axis, the name of a `TF1` function can be specified. This function will be used to map the user coordinates to the axis values and ticks. The constructor is the following:

```
TGaxis(Double_t xmin, Double_t ymin, Double_t xmax,
Double_t ymax, const char* funcname, Int_t ndiv = 510,
Option_t* chopt, Double_t gridlength = 0)
```

In such a way, it is possible to obtain exponential evolution of the tick marks position, or even decreasing. In fact, anything you like.

Orientation of tick marks on axis.

Tick marks are normally drawn on the positive side of the axis, however, if `xmin = xmax`, then negative.

- `chopt = '+'`: tick marks are drawn on Positive side. (Default)
- `chopt = '-'`: tick marks are drawn on the negative side. i.e.: `'+-'` --> tick marks are drawn on both sides of the axis.
- `chopt = 'U'`: Unlabeled axis, default is labeled.

Label Position

Labels are normally drawn on side opposite to tick marks. However, `chopt = '='`: on Equal side

Label Orientation

Labels are normally drawn parallel to the axis. However, if `xmin = xmax`, then they are drawn orthogonal, and if `ymin = ymax` they are drawn parallel.

Tick Mark Label Position

Labels are centered on tick marks. However, if `xmin = xmax`, then they are right adjusted.

- `chopt = 'R'`: labels are Right adjusted on tick mark (default is centered)
- `chopt = 'L'`: labels are left adjusted on tick mark.
- `chopt = 'C'`: labels are centered on tick mark.
- `chopt = 'M'`: In the Middle of the divisions.

Label Formatting

Blank characters are stripped, and then the label is correctly aligned. The dot, if last character of the string, is also stripped. In the following, we have some parameters, like tick marks length and characters height (in percentage of the length of the axis, in user coordinates)

The default values are as follows:

- Primary tick marks: 3.0 %
- Secondary tick marks: 1.5 %
- Third order tick marks: .75 %
- Characters height for labels: 4%
- Labels offset: 1.0 %

Optional Grid

`chopt = 'W'`: cross-Wire

Axis Binning Optimization

By default, the axis binning is optimized.

- `chopt = 'N'`: No binning optimization
- `chopt = 'I'`: Integer labeling

Time Format

Axis labels may be considered as times, plotted in a defined time format. The format is set with `SetTimeFormat()`.

`chopt = 't'`: Plot times with a defined format instead of values

The format string for date and time use the same options as the one used in the standard `strftime` C function. For the date:

- `%a` abbreviated weekday name
- `%b` abbreviated month name
- `%d` day of the month (01-31)
- `%m` month (01-12)
- `%y` year without century

For the time:

- `%H` hour (24-hour clock)
- `%I` hour (12-hour clock)
- `%p` local equivalent of AM or PM
- `%M` minute (00-59)
- `%S` seconds (00-61)

- `%%`   %

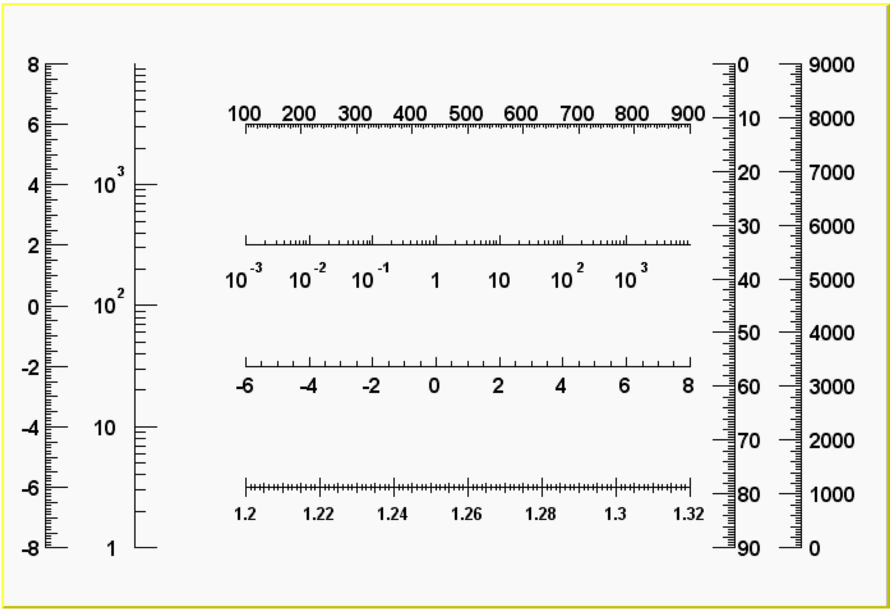
The start time of the axis will be `wmin + time offset`. This time offset is the same for all axes, since it is gathered from the active style. One may set the time offset:

```
gStyle->SetTimeOffset(time)
```

Where "`time`" is the offset time expressed in UTC (Universal Coordinated Time) and is the number of seconds since a standard date (1970), adjusted for some earth's rotation drifting. Your computer time is using UTC as a reference.

Axis Example 1:

To illustrate all what was said before, we can show two scripts. This example creates this picture:



This script goes along with it::

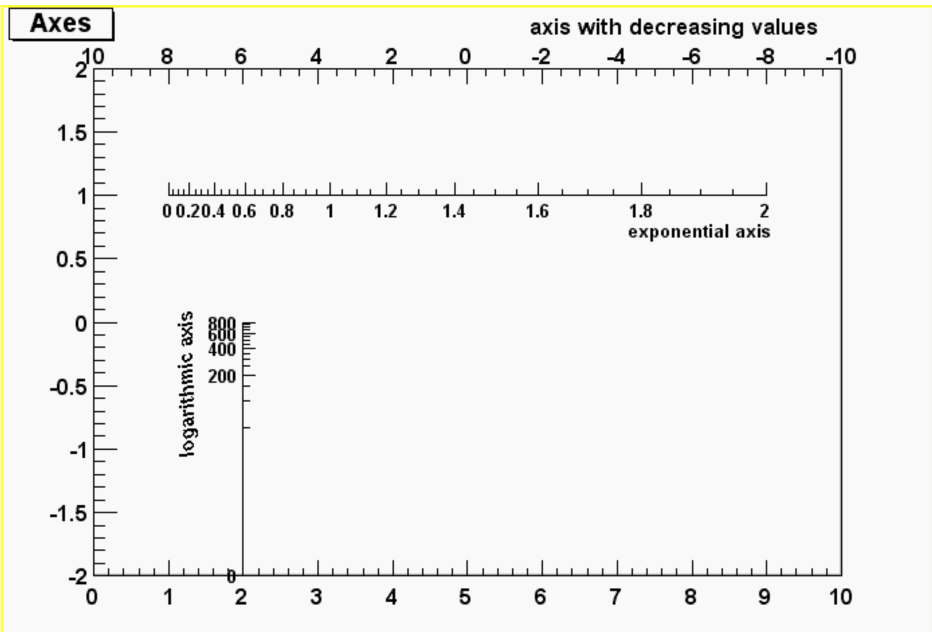
```
{
 gROOT->Reset();

 c1 = new TCanvas("c1","Examples of Gaxis",10,10,700,500);
 c1->Range(-10,-1,10,1);

 TGaxis *axis1 = new TGaxis(-4.5,-0.2,5.5,-0.2,-6,8,510,"");
 axis1->SetName("axis1");
 axis1->Draw();

 TGaxis *axis2 = new TGaxis(4.5,0.2,5.5,0.2,
                            0.001,10000,510,"G");
```

… the script is continued on the next page

```
 axis2->SetName("axis2");
 axis2->Draw();

 TGaxis *axis3 = new TGaxis(-9,-0.8,-9,0.8,-8,8,50510,"");
 axis3->SetName("axis3");
 axis3->Draw();

 TGaxis *axis4 = new TGaxis(-7,-0.8,7,0.8,1,10000,50510,"G");
 axis4->SetName("axis4");
 axis4->Draw();TGaxis *axis5 = new TGaxis(-4.5,-.6,5.5,-
.6,1.2,1.32,80506,"-+");
 axis5->SetName("axis5");
 axis5->SetLabelSize(0.03);
 axis5->SetTextFont(72);
 axis5->SetLabelOffset(0.025);
 axis5->Draw();

 TGaxis *axis6 = new TGaxis(-4.5,0.6,5.5,0.6,
                            100,900,50510,"-");
 axis6->SetName("axis6");
 axis6->Draw();

 TGaxis *axis7 = new TGaxis(8,-0.8,8,0.8,0,9000,50510,"+L");
 axis7->SetName("axis7");
 axis7->SetLabelOffset(0.01);
 axis7->Draw();

// one can make axis top->bottom. However because of a
// problem, the two x values should not be equal
 TGaxis *axis8 = new TGaxis(6.5,0.8,6.499,-0.8,
                            0,90,50510,"-");
 axis8->SetName("axis8");
 axis8->Draw();
}
```

Axis Example 2:

The second example shows the use of the second form of the constructor, with axis ticks position determined by a function `TF1`:



```
void gaxis3a()
{
   gStyle->SetOptStat(0);

   TH2F *h2 = new TH2F("h","Axes",2,0,10,2,-2,2);
   h2->Draw();

   TF1 *f1=new TF1("f1","-x",-10,10);
   TGaxis *A1 = new TGaxis(0,2,10,2,"f1",510,"-");
   A1->SetTitle("axis with decreasing values");
   A1->Draw();

   TF1 *f2=new TF1("f2","exp(x)",0,2);
   TGaxis *A2 = new TGaxis(1,1,9,1,"f2");
   A2->SetTitle("exponential axis");
   A2->SetLabelSize(0.03);
   A2->SetTitleSize(0.03);
   A2->SetTitleOffset(1.2);
   A2->Draw();

   TF1 *f3=new TF1("f3","log10(x)",0,800);
   TGaxis *A3 = new TGaxis(2,-2,2,0,"f3",505);
   A3->SetTitle("logarithmic axis");
   A3->SetLabelSize(0.03);
   A3->SetTitleSize(0.03);
   A3->SetTitleOffset(1.2);
   A3->Draw();
}
```

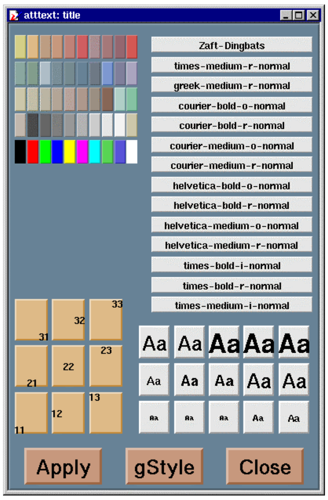
Graphical Objects Attributes

Text Attributes

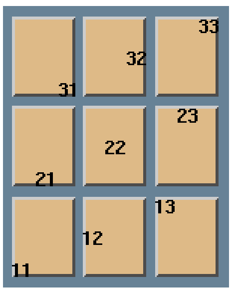
When a class contains text or derives from a text class, it needs to be able to set text attributes like font type, size, and color. To do so, the class inherits from the `TAttText` class (a secondary inheritance), which defines text attributes. `TLatex` and `TText` inherit from `TAttText`.

Setting Text Attributes Interactively

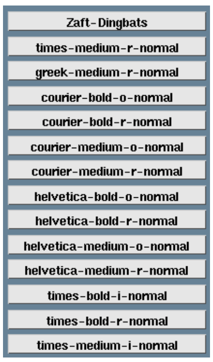
When clicking on an object containing text, one of the last items in the context menu is `SetTextAttributes`. Selecting it makes the following window appear:



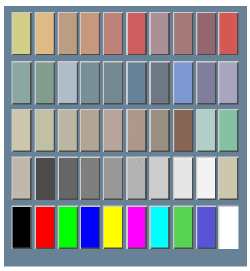
This canvas allows you to set:



The text alignment



Font



Color

Size

Setting Text Alignment

Text alignment may also be set by a method call. What is said here applies to all objects deriving from `TAttText`, and there are many. We will take an example that may be transposed to other types. Suppose "`la`" is a `TLatex` object. The alignment is set with:

```
root[] la->SetTextAlign(align)
```

The parameter `align` is a `short` describing the alignment:
align = `10*HorizontalAlign + VerticalAlign`

For Horizontal alignment the following convention applies:

- 1 = left
- 2 = centered
- 3 = right

For Vertical alignment the following convention applies:

- 1 = bottom
- 2 = centered
- 3 = top

For example

Align: 11 = left adjusted and bottom adjusted

Align: 32 = right adjusted and vertically centered

Setting Text Angle

Use `TAttText::SetTextAngle` to set the text angle. The `angle` is the degrees of the horizontal.

```
root[] la->SetTextAngle(angle)
```

Setting Text Color

Use `TAttText::SetTextCoor` to set the text color. The `color` is the color index. The colors are described in "Color and color palettes".

```
root[] la->SetTextColor(color)
```

Setting Text Font

Use `TAttText::SetTextFont` to set the font. The parameter font is the font code, combining the font and precision:

```
font = 10 * fontID + precision
```

```
root[] la->SetTextFont(font)
```

The table below lists the available fonts. The font IDs must be between 1 and 14.

The precision can be:

- Precision = 0 fast hardware fonts (steps in the size)

- Precision = 1 scalable and rotate-able hardware fonts (see below)
- Precision = 2 scalable and rotate-able hardware fonts

When precision 0 is used, only the original non-scaled system fonts are used. The fonts have a minimum (4) and maximum (37) size in pixels. These fonts are fast and are of good quality. Their size varies with large steps and they cannot be rotated.

Precision 1 and 2 fonts have a different behavior depending if True Type Fonts (TTF) are used or not. If TTF are used, you always get very good quality scalable and rotate-able fonts. However, TTF are slow.

Precision 1 and 2 fonts have a different behavior for PostScript in case of `TLatex` objects:

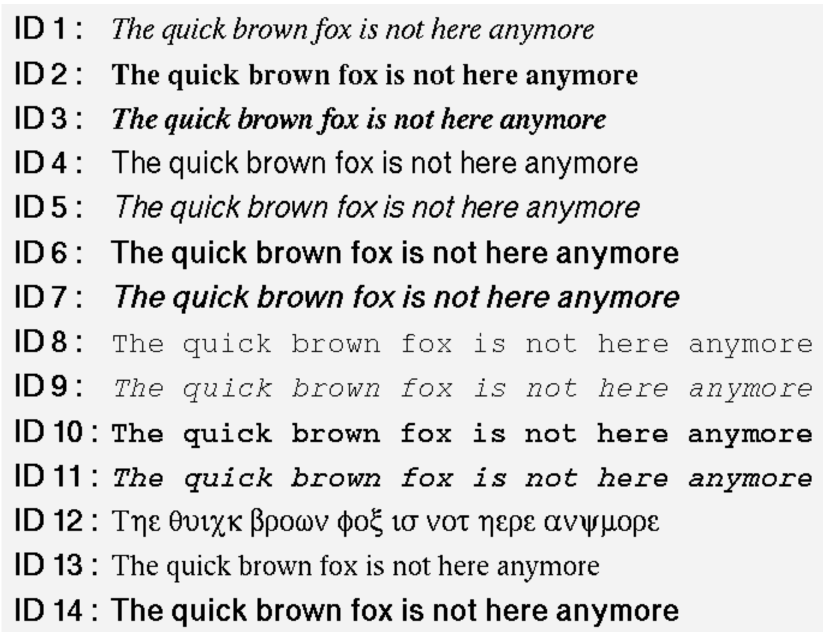
- With precision 1, the PostScript text uses the old convention (`see TPostScript`) for some special characters to draw sub and superscripts or Greek text.
- With precision 2, the "PostScript" special characters are drawn as such. To draw sub and superscripts it is highly recommended to use `TLatex` objects instead.

For example: `font = 62` is the font with ID `6` and precision `2`

The available fonts are:

Font ID	X11	True Type name	is italic	"boldness"
1	times-medium-i-normal	"Times New Roman"	Yes	4
2	times-bold-r-normal	"Times New Roman"	No	7
3	times-bold-i-normal	"Times New Roman"	Yes	7
4	helvetica-medium-r-normal	"Arial"	No	4
5	helvetica-medium-o-normal	"Arial"	Yes	4
6	helvetica-bold-r-normal	"Arial"	No	7
7	helvetica-bold-o-normal	"Arial"	Yes	7
8	courier-medium-r-normal	"Courier New"	No	4
9	courier-medium-o-normal	"Courier New"	Yes	4
10	courier-bold-r-normal	"Courier New"	No	7
11	courier-bold-o-normal	"Courier New"	Yes	7
12	symbol-medium-r-normal	"Symbol"	No	6
13	times-medium-r-normal	"Times New Roman"	No	4
14		"Wingdings"	No	4

Here is an example of what the fonts look like:



This script makes the image of the different fonts:

```
{
   textc = new TCanvas("textc","Example of text",1);
   for (int i=1;i<15;i++) {
      cid = new char[8];
      sprintf(cid,"ID %d :",i);
      cid[7] = 0;

      lid = new TLatex(0.1,1-(double)i/15,cid);
      lid->SetTextFont(62);
      lid->Draw();
      l = new TLatex(.2,1-(double)i/15,
                 "The quick brown fox is not here anymore");
      l->SetTextFont(i*10+2);
      l->Draw();
   }
}
```

How to use True Type Fonts

You can activate the True Type Fonts by adding the following line in your `.rootrc` file.

```
Unix.*.Root.UseTTFonts:     true
```

You can check that you indeed use the TTF in your Root session. When the TTF is active, you get the following message at the start of a session:

"Free Type Engine v1.x used to render TrueType fonts."

You can also check with the command:

```
gEnv->Print()
```

Setting Text Size

Use `TAttText::SetTextSize` to set the text size.

```
root[] la->SetTextSize(size)
```

The `size` is the text size expressed in percentage of the current pad size. The text size in pixels will be:

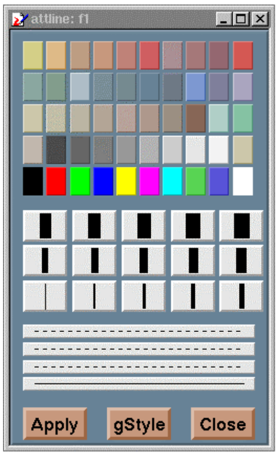
- If current pad is horizontal, the size in pixels = `textsize * canvas_height`
- If current pad is vertical, the size in pixels = `textsize * canvas_width`

Line Attributes

All classes manipulating lines have to deal with line attributes. This is done by using secondary inheritance of the class `TAttLine`.

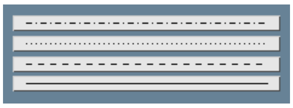
Setting Line Attributes Interactively

When clicking on an object being a line or having some line attributes, one of the last items in the context menu is `SetLineAttributes`. Selecting it makes the following window appear:

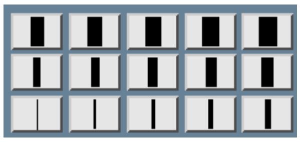


This canvas allows you to set:

The line color



Style



Width

Setting Line Color

Line color may be set by a method call. What is said here applies to all objects deriving from `TAttLine`, and there are many (histograms, plots). We will take an example that may be transposed to other types. Suppose "`li`" is a `TLine` object. The line color is set with:

```
root[] li->SetLineColor(color)
```

The argument `color` is a color number. The colors are described in "Color and Color Palettes"

Setting Line Style

Line style may be set by a method call. What is said here applies to all objects deriving from `TAttLine`, and there are many (histograms, plots). We will take an example that may be transposed to other types. Suppose "`li`" is a `TLine` object. The line style is set with:

```
root[] li->SetLineStyle(style)
```

The argument `style` is one of:

`1=solid, 2=dash, 3=dash-dot, 4=dot-dot.`

Setting Line Width

Line width may be set by a method call. What is said here applies to all objects deriving from `TAttLine`, and there are many (histograms, plots). We will take an example that may be transposed to other types. Suppose "`li`" is a `TLine` object. The line width is set with:

```
root[] li->SetLineWidth(width)
```

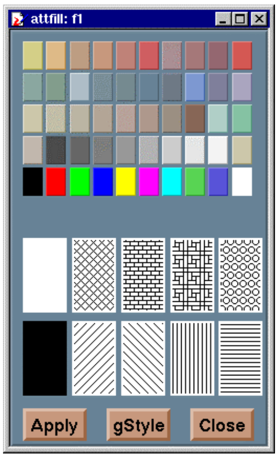
The `width` is the width expressed in pixel units.

Fill Attributes

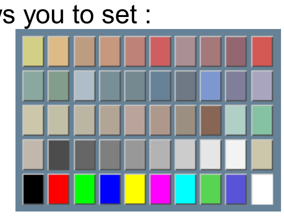
Almost all graphics classes have a fill area somewhere. These classes have to deal with fill attributes. This is done by using secondary inheritance of the class `TAttFill`.

Setting Fill Attributes interactively

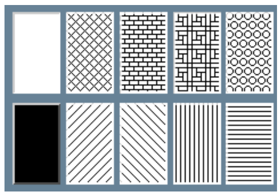
When clicking on an object having a fill area, one of the last items in the context menu is `SetFillAttributes`. Selecting it makes the following window appear:



This canvas allows you to set :



The fill color



Style

Setting Fill Color

Fill color may be set by a method call. What is said here applies to all objects deriving from `TAttFill`, and there are many (histograms, plots). We will take an example that may be transposed to other types. Suppose "`h`" is a `TH1F` (1 dim histogram) object. The histogram fill color is set with:

```
root[] h->SetFillColor(color)
```

The `color` is a color number. The colors are described in "Color and color palettes"

Setting Fill Style

Fill style may be set by a method call. What is said here applies to all objects deriving from `TAttFill`, and there are many (histograms, plots). We will take an example that may be transposed to other types. Suppose "`h`" is a `TH1F` (1 dim histogram) object. The histogram fill style is set with:

```
root[] h->SetFillStyle(style)
```

The convention for `style` is:

`0`: hollow

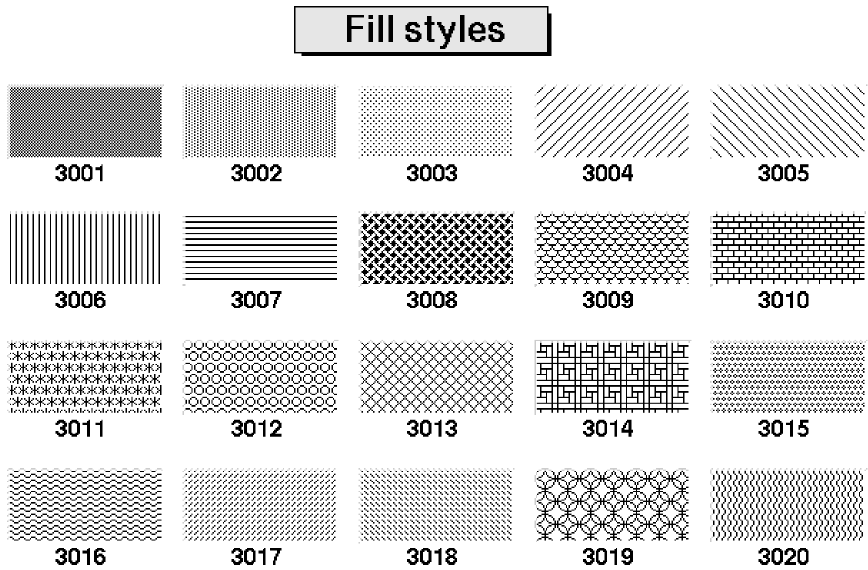
`1001`: solid

`2001`: hatch style

`3000 + pattern number`: patterns

`4000 to 4100`: transparency, `4000` = fully transparent, `4100` = fully opaque.

The various patterns are represented here:



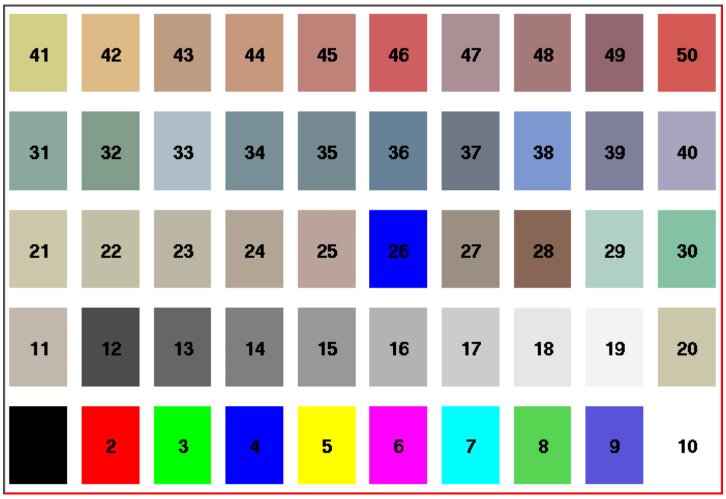
Color and Color Palettes

At initialization time, a table of basic colors is generated when the first Canvas constructor is called. This table is a linked list, which can be accessed from the `gROOT` object (see `TROOT::GetListOfColors()`). Each color has an index and when a basic color is defined, two "companion" colors are defined:

- The dark version (`color_index + 100`)

- The bright version (`color_index + 150`)

The dark and bright colors are used to give 3-D effects when drawing various boxes (see `TWbox, TPave, TPaveText, TPaveLabel`, etc).



If you have a black and white copy of the manual, here are the basic colors and their indices:

1 = black
2 = red
3 = bright green
4 = bright blue
5 = yellow
6 = hot pink
7 = aqua
8 = green
9 = blue

0 -> 9: basic colors
10 -> 19: shades of gray
20 -> 29: shades of brown
30 -> 39: shades of blue
40 -> 49: shades of red

The list of currently supported basic colors (here dark and bright colors are not shown) is shown in the picture below:

The color numbers specified in the basic palette, and the picture above, can be viewed by selecting the item "`Colors`" in the "`View`" menu of the canvas toolbar.

Other colors may be defined by the user. To do this, one has to build a new object of type `TColor`, which constructor is:

```
TColor(Int_t color, Float_t r, Float_t g, Float_t b, const
char* name)
```

One has to give the color number and the three Red, Green, Blue values, each being defined from 0 (min) to 1(max). An optional name may be given. When built, this color is automatically added to the existing list of colors.

If the color number already exists, one has to extract it from the list and redefine the `R`, `G`, `B` values. This may be done for example with:

```
root[] color = (TColor*)(gROOT->GetListOfColors()-
>At(index_color))
root[] color->SetRGB(r,g,b)
```

Where `r`, `g` and `b` go from 0 to 1 and `index_color` is the color number you wish to change.

Color Palette (for Histograms)

Defining one color at a time may be tedious. The color palette is used by the histogram classes (see Draw Options). For example, `TH1::Draw("col")` draws a 2-D histogram with cells represented by a box filled with a color `CI` function of the cell content. If the cell content is `N`, the color `CI` used will be the color number in `colors[N]`. If the maximum cell content is `> ncolors`, all cell contents are scaled to `ncolors`.

The current color palette does not have a class or global object of it's own. It is defined in the current style as an array of color numbers. One may change the current palette with the `TStyle::SetPalette(Int_t ncolors, Int_t* color_indexes)` method.

By default, or if `ncolors <= 0`, a default palette (see above) of 50 colors is defined. The colors defined in this palette are good for coloring pads, labels, and other graphic objects.

If `ncolors > 0` and `colors = 0`, the default palette is used with a maximum of `ncolors`. If `ncolors == 1 && colors == 0`, then a pretty palette with a spectrum Violet->Red is created. It is recommended to use this pretty palette when drawing legos, surfaces or contours.

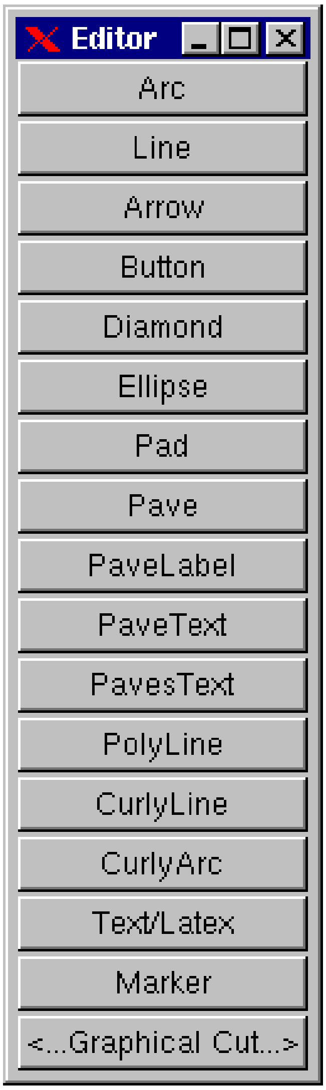
For example, to set the current palette to the "pretty" one, one has to do:

```
root[] gStyle->SetPalette(1)
```

A more complete example is shown below. It illustrates the definition of a custom palette. You can adapt it to suit your needs. In case you use it for contour coloring, with the current color/contour algorithm, always define two more colors than the number of contours.

```
void palette()
{
// Example of creating new colors (purples)
// and defining of a new palette
  const Int_t colNum = 10;
  Int_t palette[colNum];
  for (Int_t i=0;i<colNum;i++) {
    // get the color and
    // if it does not exist create
    if (! gROOT->GetColor(230+i) ){
      TColor *color = new TColor
             (230+i,1-(i/((colNum)*1.0)),0.3,0.5,"");
    } else {
      TColor *color = gROOT->GetColor(230+i);
      color->SetRGB(1-(i/((colNum)*1.0)),0.3,0.5);
    }

    palette[i] = 230+i;
  }
  gStyle->SetPalette(colNum,palette);

  TF2 *f2 = new TF2("f2","exp(-(x^2)-(y^2))",-3,3,-3,3);
  // two contours less than the
  // number of colors in palette
  f2->SetContour(colNum-2);
  f2->Draw("cont");
}
```

The Graphical Editor



ROOT has a built-in graphics editor to draw and edit graphic primitives starting from an empty canvas or on top of a picture (e.g. histogram). The editor is started by selecting the "`Editor`" item in the canvas "`Edit`" menu. A menu appears into an independent window.

You can create the following graphical objects:

An arc or circle: Click on the center of the arc, and then move the mouse. A rubber band circle is shown. Click again with the left button to freeze the arc.

A line or an arrow: Click with the left button at the point where you want to start the arrow, then move the mouse and click again with the left button to freeze the arrow.

A Diamond: Click with the left button and freeze again with the left button. The editor draws a rubber band box to suggest the outline of the diamond.

An Ellipse: Proceed like for an arc. You can grow/shrink the ellipse by pointing to the sensitive points. They are highlighted. You can move the ellipse by clicking on the ellipse, but not on the sensitive points. If, with the ellipse context menu, you have selected a fill area color, you can move a filled-ellipse by pointing inside the ellipse and dragging it to its new position. Using the context menu, you can build an arc of ellipse and tilt the ellipse.

A Pad: Click with the left button and freeze again with the left button. The editor draws a rubber band box to suggest the outline of the pad.

A Pave Label: Proceed like for a pad. Type the text to be put in the box. Then type a carriage return. The text will be redrawn to fill the box.

A Pave Text or Paves Text: Proceed like for a pad. You can then click on the `TPaveText` object with the right mouse button and select the option `AddText`.

A Poly Line: Click with the left button for the first point, move the moose, click again with the left button for a new point. Close the poly-line with a double click. To edit one vertex point, pick it with the left button and drag to the new point position.

A CurlyLine: Proceed as for the arrow/line. Once done, click with the third button to change the characteristics of the curly line, like transform it to wave, change the wavelength, etc…

A CurlyArc: Proceed like for the arrow/line. The first click is located at the position of the center, the second click at the position of the arc beginning. Once done, one obtains a curly ellipse, for which one can click with the third button to change the characteristics, like transform it to wavy, change the wavelength, set the minimum and maximum angle to make an arc that is not closed, etc…

A Text /Latex string: Click with the left button where you want to draw the text, then type in the text terminated by carriage return. All `TLatex` expressions are valid. To move the text or formula, point on it keeping the left mouse button pressed and drag the text to its new position. You can grow/shrink the text if you position the mouse to the first top-third part of the string, then move the mouse up or down to grow or shrink the text respectively. If you position the mouse near the bottom-end of the text, you can rotate it.

A Marker: Click with the left button where to place the marker. The marker can be modified by `gStyle->SetMarkerStyle()`.

A Graphical Cut: Click with the left button on each point of a polygon delimiting the selected area. Close the cut by double clicking on the last point. A `TCutG` object is created. It can b e used as a selection for a `TTree::Draw`. You can get a pointer to this object with `TCutG cut = (TCutG*) gPad->GetPrimitive("CUTG")`.

Once you are happy with your picture, you can select the `Save as canvas.C` item in the canvas `File` menu. This will automatically generate a script with the C++ statements corresponding to the picture. This facility also works if you have other objects not drawn with the graphics editor (histograms for example).

Copy/Paste With DrawClone

You can make a copy of a canvas using `TCanvas::DrawClonePad`. This method is unique to `TCanvas`. It clones the entire canvas to the active pad. There is a more general method `TObject::DrawClone`, which all objects descendents of `TObject`, specifically all graphic objects inherit. Below are two examples, one to show the use of `DrawClonePad` and the other to show the use of `DrawClone`.

Example 1: TCanvas::DrawClonePad

In this example we will copy an entire canvas to a new one with `DrawClonePad`.

Run the script `draw2dopt.C`.

```
root [] .x tutorials/draw2dopt.C
```

This creates a canvas with 2D histograms. To make a copy of the canvas follows these steps

Right-click on it to bring up the context menu.

Select `DrawClonePad`.

This copies the entire canvas and all its sub-pads to a new canvas. The copied canvas is a deep clone, and all the objects on it are copies and independent of the original objects. For instance, change the fill on one of the original histograms, and the cloned histogram retains its attributes.

`DrawClonePad` will copy the canvas to the active pad; the target does not have to be a canvas. It can also be a pad on a canvas.

Example 2: TObject::DrawClone

If you want to copy and paste a graphic object from one canvas or pad to another canvas or pad, you can do so with `DrawClone` method inherited from `TObject`. The `TObject::DrawClone` method is inherited by all graphics objects.

In this example, we create a new canvas with one histogram from each of the canvases from the script `draw2dopt.C`.

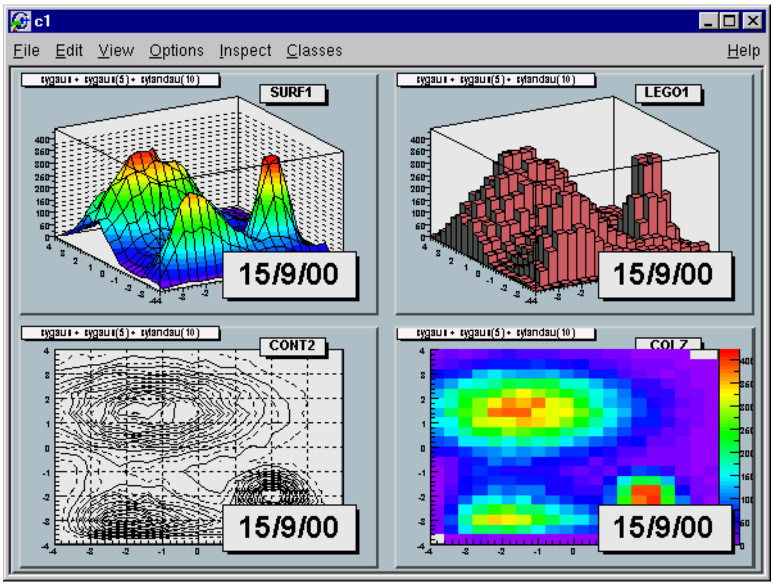
1. Start a new ROOT session and execute the script `draw2dopt.C`
2. Select a canvas displayed by the script, and create a new canvas from the File menu (`c1`).
3. Make sure that the target canvas (`c1`) is the active one by middle clicking on it. If you do this step right after step 2, c1 will be active.
4. Select the pad with the first histogram you want to copy and paste.
5. Right click on it to show the context menu, and select `DrawClone`.
6. Leave the option blank and hit OK.

Repeat these steps for one histogram on each of the canvases created by the script, until you have one pad from each type.

If you wanted to put the same annotation on each of the sub pads in the new canvas, you could use `DrawClone` to do so. Here we added the date to each pad. The steps to this are:

1. Create the label in on of the pads with the graphics editor.
2. Middle-click on the target pad to make it the active pad
3. Use `DrawClone` method of the label to draw it in each of the other panels.

The option in the `DrawClone` method argument is the Draw option for a histogram or graph. A call to `TH1::DrawClone` can clone the histogram with a different draw option.



Copy/Paste Programmatically

To copy and paste the four pads from the command line or in a script you would execute the following statements:

```
root [] .x tutorials/draw2dopt.C
root [] TCanvas c1("c1","Copy Paste",200,200,800,600);
root [] surfaces->cd(1);        // get the first pad
root [] TPad * p1 = gPad;
root [] lego->cd(2);            // get the next pad
root [] TPad * p2 = gPad;
root [] cont->cd(3);            // get the next pad
root [] TPad * p3 = gPad;
root [] c2h->cd(4);             // get the next pad
root [] TPad * p4 = gPad;
root []                         // draw the four clones
root [] c1->cd();
root [] p1->DrawClone();
root [] p2->DrawClone();
root [] p3->DrawClone();
root [] p4->DrawClone();
```

Note that the pad is copied to the new canvas in the same location as in the old canvas. For example if you were to copy the third pad of `surf` to the top left corner of the target canvas you would have to reset the coordinates of the cloned pad.

Legends

Legends for a graph are obtained with a `TLegend` object. This object points to markers/lines/boxes/histograms/graphs and represent their marker/line/fill attribute. Any object that has a marker or line or fill attribute may have an associated legend.

A `TLegend` is a panel with several entries (class `TLegendEntry`) and is created by the constructor

```
TLegend( Double_t x1, Double_t y1,Double_t x2, Double_t y2,
const char *header, Option_t *option)
```

The legend is defined with default coordinates, border size and option `x1,y1,x2,y2` are the coordinates of the legend in the current pad (in NDC coordinates by default). The default text attributes for the legend are:

- Alignment = 12 left adjusted and vertically centered
- Angle = 0 (degrees)
- Color = 1 (black)
- Size = calculate when number of entries is known
- Font = helvetica-medium-r-normal scalable font = 42, and bold = 62 for title

The title It is a regular entry and supports `TLatex`. The default is no title (`header = 0`). The options are the same as for `TPave`; by default, they are "`brNDC`".

Once the legend box is created, one has to add the text with the `AddEntry()` method:

```
TLegendEntry* TLegend::AddEntry(TObject *obj, const char
*label, Option_t *option)
```

The parameters are:

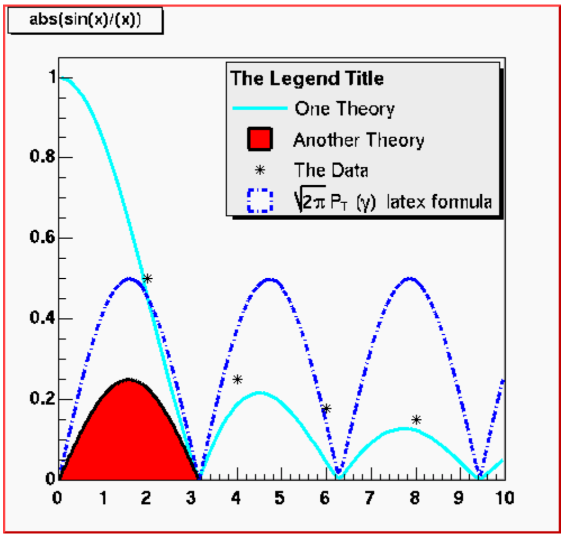
- `*obj`: is a pointer to an object having marker, line, or fill attributes (for example a histogram, or graph)
- `label`: is the label to be associated to the object
- `option`:
  - ”`L`” draw line associated with line attributes of `obj` if `obj` has them (inherits from `TAttLine`)
  - ”`P`” draw poly-marker associated with marker attributes of `obj` if `obj` has them (inherits from `TAttMarker`)
  - ”`F`” draw a box with fill associated with fill attributes of `obj` if `obj` has them (inherits `TAttFill`)

One may also use the other form of `AddEntry`:

```
TLegendEntry* TLegend::AddEntry(const char *name, const
char *label, Option_t *option)
```

Where `name` is the name of the object in the pad. Other parameters are as in the previous case.

Here's an example of a legend created with `TLegend`



The legend part of this plot was created as follows:

```
leg = new TLegend(0.4,0.6,0.89,0.89);
leg->AddEntry(fun1,"One Theory","l");
leg->AddEntry(fun3,"Another Theory","f");
leg->AddEntry(gr,"The Data","p");
leg->Draw();
// oops we forgot the blue line... add it after
leg->AddEntry(fun2,
      "#sqrt{2#pi} P_{T} (#gamma) latex  formula","f");
// and add a header (or "title") for the legend
leg->SetHeader("The Legend Title");
leg->Draw();
```

Where `fun1,fun2,fun3` and `gr` are pre-existing functions and graphs. You can edit the `TLegend` by right clicking on it.

The PostScript Interface

To generate a PostScript (or encapsulated PostScript) file for a single image in a canvas, you can:

Select the “`Print PostScript`“ item in the canvas “`File`“ menu. By default, a PostScript file called `canvas.ps` is generated.

Click in the canvas area, near the edges, with the right mouse button and select the “`Print`“ item. You can select the name of the PostScript file. If the file name is `xxx.ps`, you will generate a PostScript file named `xxx.ps`. If the file name is `xxx.eps`, you generate an encapsulated Postscript file instead.

In your program (or script), you can type:

```
c1->Print("xxx.ps")
```

Or

```
c1->Print("xxx.eps")
```

This will generate a file of canvas pointed to by `c1`.

```
pad1->Print("xxx.ps")
```

This prints the picture in the pad pointed by `pad1`.

The `TPad::Print` method has a second parameter called option. Its value can be:

- `0` which is the default and is the same as "ps"
- `"ps"` a Postscript file is produced
- `"eps"` an Encapsulated Postscript file is produced
- `"gif"` a GIF file is produced
- `"cxx"` a C++ macro file is produced

You do not need to specify the second parameter, you can indicate by the filename extension what format you want to save a canvas in (i.e. `canvas.ps, canvas.gif, canvas.C`, etc).

The size of the PostScript picture, by default, is computed to keep the aspect ratio of the picture on the screen, where the size along `x` is always 20 cm.

You can set the size of the PostScript picture before generating the picture with a command such as:

```
TPostScript myps("myfile.ps",111)
myps.Range(xsize,ysize);
object->Draw();
myps.Close();
```

The first parameter in the `TPostScript` constructor is the name of the file. The second parameter is the format option.

- 111 - ps portrait
- 112 - ps landscape
- 113 - eps

You can set the default paper size with:

```
gStyle->SetPaperSize(xsize,ysize);
```

You can resume writing again in this file with `myps.Open()`. Note that you may have several Post Script files opened simultaneously.

To add text to a postscript file, use the method `TPostScript::Text( x,y,"string")`. This method write the string in quotes into a PostScript file at position x,y in world coordinates.

Special Characters

The following characters have a special action on the PostScript file:

`` ` ``: Go to Greek

`'`: Go to special

`~`: Go to Zapf Dingbats

`?` : Go to subscript

`^`: Go to superscript

`!`: go to normal level of script

`&`: Backspace one character

`#`: End of Greek or of Zapf Dingbats

These special characters are printed as such on the screen. To generate one of these characters on the PostScript file, you must escape it with the escape character "`@`".

The use of these special characters is illustrated in several scripts referenced by the `TPostScript` constructor.

Multiple Pictures in a PostScript File: Case 1

The following script is an example illustrating how to open a PostScript file and draw several pictures. The generation of a new PostScript page is automatic when `TCanvas::Clear` is called by `object->Draw()`.

```
{
   TFile f("hsimple.root");
   TCanvas c1("c1","canvas",800,600);

//select PostScript  output type
   Int_t type = 111;   //portrait  ps
// Int_t type = 112;   //landscape ps
// Int_t type = 113;   //eps

//create a PostScript  file and set the paper size
   TPostScript ps("test.ps",type);
   ps.Range(16,24);  //set x,y of printed page

//draw 3 histograms from file hsimple.root on separate pages
   hpx->Draw();
   c1.Update();       //force drawing in a script
   hprof->Draw();
   c1.Update();
   hpx->Draw("lego1");
   c1.Update();
   ps.Close();
}
```

Multiple Pictures a PostScript File: Case 2

This example shows 2 pages. The canvas is divided. `TPostScript::NewPage` must be called before starting a new picture. `object->Draw` does not clear the canvas in this case because we clear only the pads and not the main canvas. Note that `c1->Update` must be called at the end of the first picture.

```
{
   TFile *f1 = new TFile("hsimple.root");
   TCanvas *c1 = new TCanvas("c1");
   TPostScript *ps = new TPostScript("file.ps",112);
   c1->Divide(2,1);
// picture 1
   ps->NewPage();
   c1->cd(1);
   hpx->Draw();
   c1->cd(2);
   hprof->Draw();
   c1->Update();
// picture 2
   ps->NewPage();
   c1->cd(1);
   hpxpy->Draw();
   c1->cd(2);
   ntuple->Draw("px");
   c1->Update();
   ps->Close();
// invoke PostScript  viewer
   gSystem->Exec("gs file.ps");
}
```

Create or Modify a Style

All objects that can be drawn in a pad inherit from one or more attribute classes like `TAttLine, TAttFill, TAttText, TAttMarker`. When the objects are created, their default attributes are taken from the current style. The current style is an object of the class `TStyle` and can be referenced via the global variable `gStyle` (in `TStyle.h`). See the class `TStyle` for a complete list of the attributes that can be set in one style. ROOT provides several styles called

- "`Default`" The default style
- "`Plain`" The simple style (black and white)
- "`Bold`" Bolder lines
- "`Video`" Suitable for html output or screen viewing

The "`Default`" style is created by:

```
TStyle *default = new TStyle("Default","Default Style");
```

The "`Plain`" style can be used if you are working on a monochrome display or if you want to get a "conventional" PostScript output. As an example, these are the instructions in the ROOT constructor to create the "`Plain`" style.

```
TStyle *plain  = new TStyle("Plain","Plain Style (no
colors/fill areas)");

   plain->SetCanvasBorderMode(0);
   plain->SetPadBorderMode(0);
   plain->SetPadColor(0);
   plain->SetCanvasColor(0);
   plain->SetTitleColor(0);
   plain->SetStatColor(0);
```

You can set the current style with:

```
gROOT->SetStyle(style_name);
```

You can get a pointer to an existing style with:

```
TStyle *style = gROOT->GetStyle(style_name);
```

You can create additional styles with:

```
TStyle *st1 = new TStyle("st1","my style");
st1->Set....
st1->cd();  // this becomes now the current style gStyle
```

In your `rootlogon.C` file, you can redefine the default parameters via statements like:

```
gStyle->SetStatX(0.7);
gStyle->SetStatW(0.2);
gStyle->SetLabelOffset(1.2);
gStyle->SetLabelFont(72);
```

Note that when an object is created, its attributes are taken from the current style. For example, you may have created a histogram in a previous session and saved it in a file. Meanwhile, if you have changed the style, the histogram will be drawn with the old attributes. You can force the current style attributes to be set when you read an object from a file by calling `ForceStyle` before reading the objects from the file.

```
gROOT->ForceStyle();
```

When you call `gROOT->ForceStyle()` and read an object from a ROOT file, the objects method `UseCurrentStyle` is called. The attributes saved with the object are replaced by the current style attributes. You call also call `myObject->UseCurrentStyle()` directly. For example if you have a canvas or pad with your histogram or any other object, you can force these objects to get the attributes of the current style with:

```
canvas->UseCurrentStyle();
```

The description of the style functions should be clear from the name of the `TStyle` setters or getters. Some functions have an extended description, in particular:

- `TStyle::SetLabelFont`
- `TStyle::SetLineStyleString`: set the format of dashed lines.
- `TStyle::SetOptStat`
- `TStyle::SetPalette` to change the colors palette
- `TStyle::SetTitleOffset`

9 Input/Output

This chapter covers the saving and reading of objects to and from ROOT files. It begins with an explanation of the physical layout of a ROOT file. It includes a discussion on compression, and file recovery. Then we explain the logical file, the class `TFile` and its methods. We show how to navigate in a file, how to save objects and read them back. We also include a discussion on Streamers. Streamers are the methods responsible to capture an objects current state to save it to disk or send it over the network. At the end of the chapter is a discussion on the two specialized ROOT files: `TNetFile` and `TWebFile`.

The Physical Layout of ROOT Files

A ROOT file is like a UNIX file directory. It can contain directories and objects organized in unlimited number of levels. It also is stored in machine independent format (ASCII, IEEE floating point, Big Endian byte ordering).

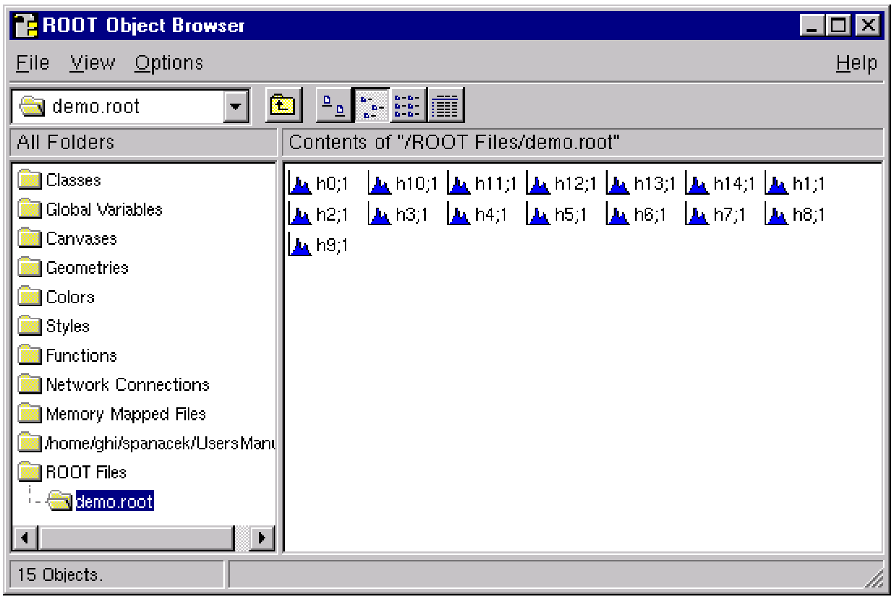
To look at the physical layout of a ROOT file, we first create one. This example creates a ROOT file and 15 histograms, fills each histogram with 1000 entries from a gaussian distribution, and writes them to the file.

```
{
   TFile f("demo.root","recreate");
   char name[10], title[20];
   for (Int_t i = 0; i < 15; i++) {
      sprintf(name,"h%d",i);
      sprintf(title,"histo nr:%d",i);
      TH1F *h = new TH1F(name,title,100,-4,4);
      h->FillRandom("gaus",1000);
      h->Write();
   }
   f.Close();
}
```

The example begins with a call to the `TFile` constructor. `TFile` is the class describing the ROOT file. In the next section, when we discuss the logical file structure, we will cover `TFile` in detail. You can also see that the file has the extension `".root"`, this convention is encouraged, however ROOT does not depend on it.

The last line of the example closed the file. To view its contents it needs to be opened again, and once opened we can view the contents in the ROOT Object browser by creating a `TBrowser` object.

```
root [] TFile f("demo.root")
root [] TBrowser browser;
```



In the browser, we can see the 15 histograms we created.

Once we have the `TFile` object, we can call the `TFile::Map()` method to view the physical layout. The output of `Map()` prints the date/time, the start address of the record, the number of bytes in the record, the class name of the record, and the compression factor.

```
root [] f.Map()
20000719/093453  At:64       N=84     TFile
20000719/093453  At:148      N=353    TH1F         CX =  2.42
20000719/093453  At:501      N=351    TH1F         CX =  2.44
20000719/093453  At:852      N=340    TH1F         CX =  2.52
20000719/093453  At:1192     N=345    TH1F         CX =  2.48
20000719/093453  At:1537     N=343    TH1F         CX =  2.50
20000719/093453  At:1880     N=358    TH1F         CX =  2.39
20000719/093453  At:2238     N=342    TH1F         CX =  2.50
20000719/093453  At:2580     N=355    TH1F         CX =  2.41
20000719/093453  At:2935     N=356    TH1F         CX =  2.40
20000719/093453  At:3291     N=346    TH1F         CX =  2.47
20000719/093453  At:3637     N=347    TH1F         CX =  2.48
20000719/093453  At:3984     N=353    TH1F         CX =  2.44
20000719/093453  At:4337     N=355    TH1F         CX =  2.42
20000719/093453  At:4692     N=344    TH1F         CX =  2.50
20000719/093453  At:5036     N=345    TH1F         CX =  2.49
20000719/093453  At:5381     N=732    TFile
20000719/093453  At:6113     N=53     TFile
```

We see our fifteen histograms (`TH1F's`) with the first one starting at byte 148. We also see several entries for `TFile`. You may notice that the first entry starts at byte 64. The first 64 bytes are taken by the file header.

This table shows the file header information:

File Header Information		
Byte	Value Name	Description
1 -> 4	"`root`"	Root file identifier
5 -> 8	`fVersion`	File format version
9 -> 12	`fBEGIN`	Pointer to first data record
13 -> 16	`fEND`	Pointer to first free word at the EOF
17 -> 20	`fSeekFree`	Pointer to FREE data record
21 -> 24	`fNbytesFree`	Number of bytes in FREE data record
25 -> 28	`nfree`	Number of free data records
29 -> 32	`fNbytesName`	Number of bytes in TNamed at creation time
33 -> 33	`fUnits`	Number of bytes for file pointers
34 -> 37	`fCompress`	Zip compression level

The first four bytes of the file header contain the string "root" which identifies a file as a ROOT file. Because of this identifier, ROOT is not dependent on the "`.root`" extension. It is still a good idea to use the extension, just for us to recognize them easier.

The `nfree` and value is the number of free records. A ROOT file has a maximum size of 2 gigabytes. This variable along with `FNBytesFree` keeps track of the free space in terms of records and bytes. This count also includes the deleted records, which are available again.

The 84 bytes after the file header contain the top directory description, including the name, the date and time it was created, and the date and time, it was last modified.

```
20000719/093453  At:64         N=84         TFile
```

What follows are the 15 histograms, in records of variable length.

```
20000719/093453  At:148     N=353       TH1F           CX =  2.42
20000719/093453  At:501     N=351       TH1F           CX =  2.44
…
20000719/093453  At:5036    N=345       TH1F           CX =  2.49
```

The first four bytes of each record is an integer holding the number of bytes in this record. A negative number flags the record as deleted, and makes the space available for recycling in the next write. The rest of bytes in the header contain all the information to uniquely identify a data block on the file. This is followed by the object data.

This table explains the values in each individual record:

Record Information		
Byte	Value Name	Description
1 -> 4	`Nbytes`	Length of compressed object (in bytes)
5 -> 6	`Version`	`TKey` version identifier
7 -> 10	`ObjLen`	Length of uncompressed object
11 -> 14	`Datime`	Date and time when object was written to file
15 -> 16	`KeyLen`	Length of the key structure (in bytes)
17 -> 18	`Cycle`	Cycle of key
19 -> 22	`SeekKey`	Pointer to record itself (consistency check)
23 -> 26	`SeekPdir`	Pointer to directory header
27	`lname`	Number of bytes in the class name
28->..	`ClassName`	Object Class Name
..->..	`lname`	Number of bytes in the object name
..->..	`Name`	`lName` bytes with the name of the object
..->..	`lTitle`	Number of bytes in the object title
..->..	`Title`	Title of the object
----->	`DATA`	Data bytes associated to the object

You see a reference to `TKey`. It is explained in detail in the next section.

The last two entries on the output of `TFile::Map()` are also for `TFile`. When a file is closed, it writes a linked list of keys at the end of the file. This is what we see in the second to last entry. In our example, the list of keys is stored in 732 bytes beginning at byte# 5381.

The last entry is a list of free blocks. In our case, this starts at 6113 and is not very long, only 53 bytes, since we have not deleted any objects.

```
…
20000719/093453  At:5381      N=732       TFile
20000719/093453  At:6113      N=53        TFile
```

This is a picture of a ROOT file, showing the file header, record headers, and object data.

File Recovery

A file may become corrupted or it may be impossible to write it to disk and close it properly. For example if the file is too large and exceeds the disk quota, or the job crashes or a batch job reaches its time limit before the file can be closed. In these cases, it is imperative to recover and retain as much information as possible. ROOT provides an intelligent and elegant file recovery mechanism using the redundant directory information in the record header.

If the file is not closed due to for example exceeded the time limit, and it is opened again, it is scanned and rebuilt according to the information in the record header. The recovery algorithm reads the file and creates the saved objects in memory according to the header information. It then rebuilds the directory and file structure.

If the file is opened in write mode, the recovery makes the correction on disk when the file is closed; however if the file is opened in read mode, the correction can not be written to disk. You can also explicitly invoke the recovery procedure by calling the `TFile::Recover()` method.

You must be aware of the 2GB size limit before you attempt a recovery. If the file has reached this limit, you cannot add more data. You can still recover the directory structure, but you cannot save what you just recovered to the file on disk.

You can also explicitly invoke the recovery procedure by calling the `TFile::Recover()` method.

Here we interrupted and aborted the previous ROOT session, causing the file not to be closed. When we start a new session and attempt to open the file, it gives us an explanation and status on the recovery attempt.

```
root [] TFile f("demo.root")
Warning in <TFile::TFile>: file demo.root probably not
closed, trying to recoverWarning in <TFile::Recover>:
successfully recovered 15 keys
```

Compression

ROOT uses a compression algorithm based on the well-known `gzip` algorithm. This algorithm supports up to nine levels of compression, and the default ROOT uses is one. The level of compression can be modified by calling the `TFile::SetCompressionLevel()` method. If the level is set to zero, no compression is done. Experience with this algorithm indicates a compression factor of 1.3 for raw data files and around two on most DST files is the optimum. The choice of one for the default is a compromise between the time it takes to read and write the object vs. the disk space savings.

The time to uncompress an object is small compared to the compression time and is independent of the selected compression level. Note that the compression level may be changed at any time, but the new compression level will only apply to newly written objects. Consequently, a ROOT file may contain objects with different compression levels.

Compression level	Bytes	Write Time (sec)	Read Time (sec.)
0	1,004,998	4.77	0.07
1	438,366	6.67	0.05
5	429,871	7.03	0.06
9	426,899	8.47	0.05

This table shows four runs of the demo script that creates 15 histograms with different compression parameters. To make the numbers more significant, the macro was modified to create 1000 histograms.

There is another example of using compression and it's impact, especially on TTrees in the chapter "The Tutorials and Tests".

The Logical ROOT File: TFile and TKey

We saw that the `TFile::Map()` method reads the file sequentially and prints information about each record while scanning the file. It is not feasible to only support sequential access and hence ROOT provides random or direct access, i.e. reading a specified object at a time. To do so, `TFile` keeps a list of `TKeys`, which is essentially an index to the objects in the file. The `TKey` class describes the record headers of objects in the file. For example, we can get the list of keys and print them. To find a specific object on the file we can use the `TFile::Get()` method.

```
root [] TFile f("demo.root")
root [] f.GetListOfKeys()->Print()
TKey Name = h0, Title = histo nr:0, Cycle = 1
TKey Name = h1, Title = histo nr:1, Cycle = 1
TKey Name = h2, Title = histo nr:2, Cycle = 1
TKey Name = h3, Title = histo nr:3, Cycle = 1
TKey Name = h4, Title = histo nr:4, Cycle = 1
TKey Name = h5, Title = histo nr:5, Cycle = 1
TKey Name = h6, Title = histo nr:6, Cycle = 1
TKey Name = h7, Title = histo nr:7, Cycle = 1
TKey Name = h8, Title = histo nr:8, Cycle = 1
TKey Name = h9, Title = histo nr:9, Cycle = 1
TKey Name = h10, Title = histo nr:10, Cycle = 1
TKey Name = h11, Title = histo nr:11, Cycle = 1
TKey Name = h12, Title = histo nr:12, Cycle = 1
TKey Name = h13, Title = histo nr:13, Cycle = 1
TKey Name = h14, Title = histo nr:14, Cycle = 1
root [] TH1F *h9 = (TH1F*)f.Get("h9");
```

The `TFile::Get()` finds the `TKey` object with name "`h9`". Using the `TKey` info it will import in memory the object in the file at the file address #3352 (see the output from the `TFile::Map` above). This is done by the `Streamer` method that is covered in detail in a later section.

Since the keys are available in a `TList` of `TKeys` we can iterate over the list of keys:

```
{
  TFile f("demo.root");
  TIter next(f.GetListOfKeys());
  TKey *key;
  while ((key=(TKey*)next())) {
    printf(
     "key: %s points to an object of class: %s at %d\n",
     key->GetName(),
     key->GetClassName(),key->GetSeekKey()
    );
  }
}
```

The output of this script is:

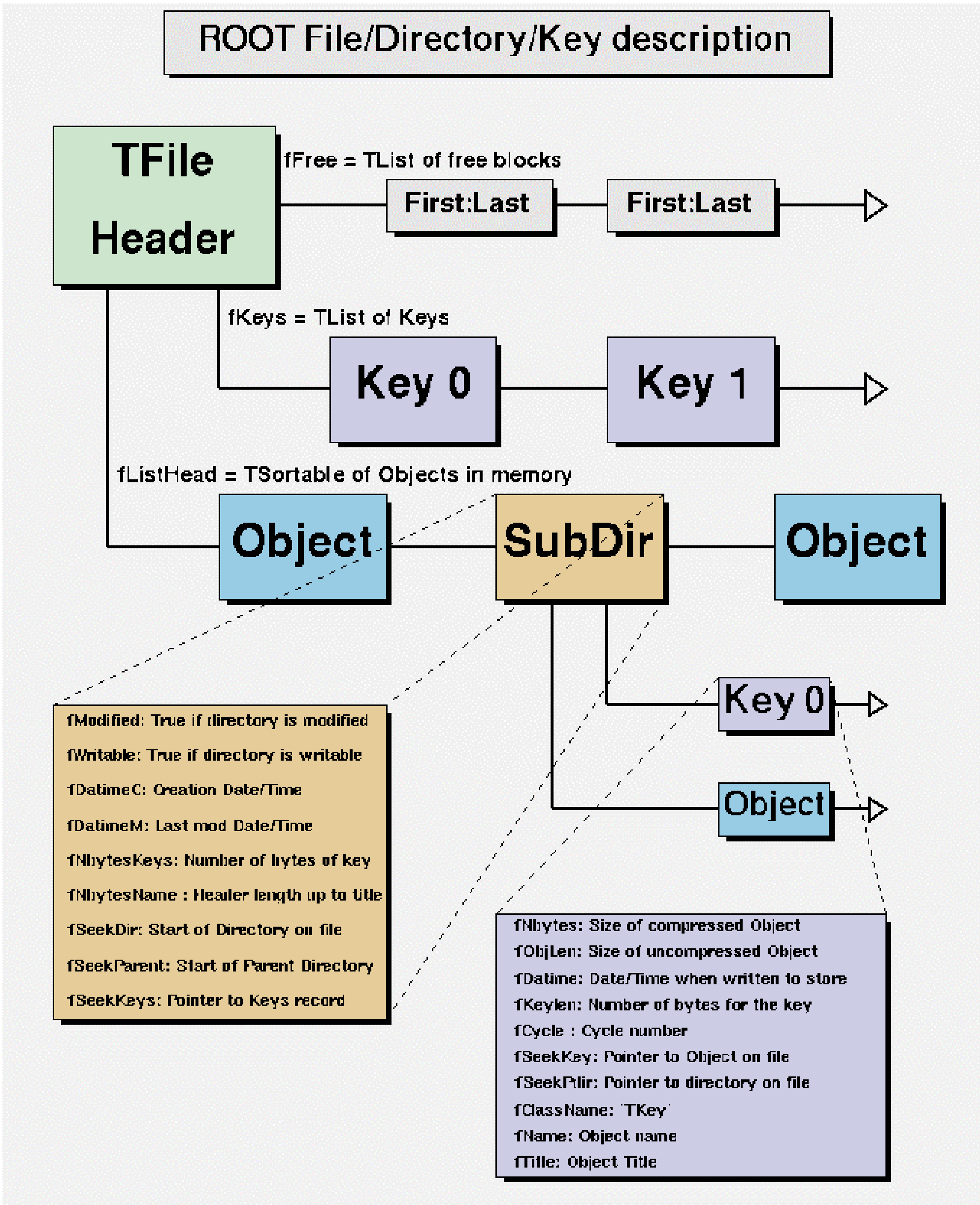
```
root [] .x iterate.C
key: h0 points to an object of class: TH1F at 150
key: h1 points to an object of class: TH1F at 503
key: h2 points to an object of class: TH1F at 854
key: h3 points to an object of class: TH1F at 1194
key: h4 points to an object of class: TH1F at 1539
key: h5 points to an object of class: TH1F at 1882
key: h6 points to an object of class: TH1F at 2240
key: h7 points to an object of class: TH1F at 2582
key: h8 points to an object of class: TH1F at 2937
key: h9 points to an object of class: TH1F at 3293
key: h10 points to an object of class: TH1F at 3639
key: h11 points to an object of class: TH1F at 3986
key: h12 points to an object of class: TH1F at 4339
key: h13 points to an object of class: TH1F at 4694
key: h14 points to an object of class: TH1F at 5038
```

In addition to the list of keys, `TFile` also keeps two other lists:

`TFile::fFree` is a `TList` of free blocks used to recycle freed up space in the file. ROOT tries to find the best free block. If a free block matches the size of the new object to be stored, the object is written in the free block and this free block is deleted from the list. If not, the first free block bigger than the object is used.

`TFile::fListHead` contains a sorted list (`TSortedList`) of objects in memory.

The diagram below illustrates the logical view of the `TFile` and `TKey`.



Viewing the Logical File Contents

`TFile` is a descendent of `TDirectory`, which means it behaves like a `TDirectory`. We can list the contents, print the name, and create subdirectories. In a ROOT session, you are always in a directory and the directory you are in is called the current directory and is stored in the global variable ***`gDirectory`***.

Let's look at a more detailed example of a ROOT file and its role as the current directory. First, we create a ROOT file by executing a sample script.

```
root [] .x $ROOTSYS/tutorials/hsimple.C
```

Now you should have `hsimple.root` in your directory. The file was closed by the script so we have to open it again to work with it.

We open the file with the intent to update it, and list its contents.

```
root [] TFile f ("hsimple.root", "UPDATE")
root [] f.ls()
TFile** hsimple.root
TFile* hsimple.root
KEY: TH1F hpx;1 This is the px distribution
KEY: TH2F hpxpy;1 py vs px
KEY: TProfile hprof;1 Profile of pz versus px
KEY: TNtuple ntuple;1 Demo ntuple
```

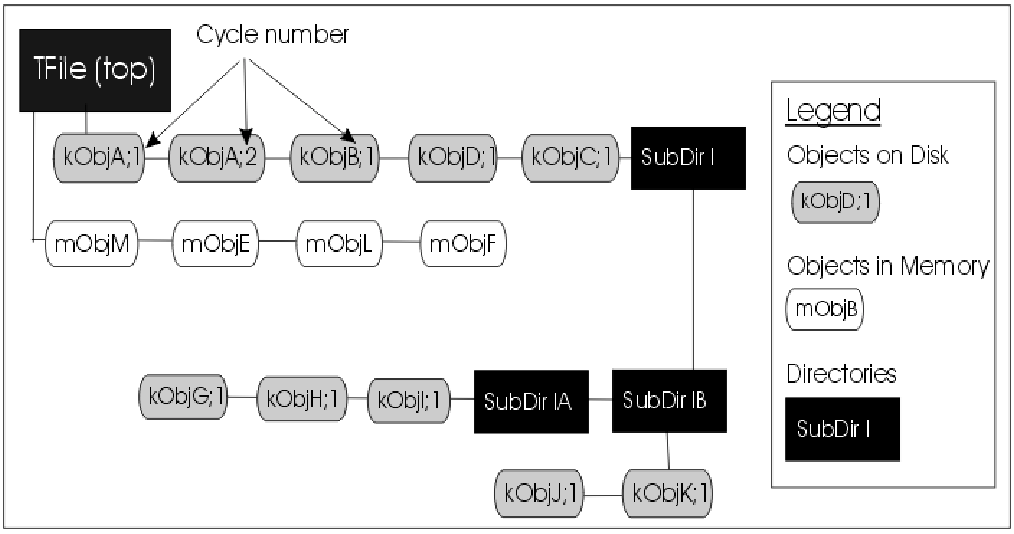
It shows the two lines starting with `TFile` followed by four lines starting with the word "KEY". The four keys tell us that there are four objects on disk in this file. The syntax of the listing is:

```
KEY: <class> <variable>;<cycle number> <title>
```

For example, the first line in the list means there is an object in the file on disk, called `hpx`. It is of the class TH1F (one-dimensional histogram of floating numbers). The object's title is "This is the `px` distribution".

If the line starts with OBJ, the object is in memory. The <class> is the name of the ROOT class (T-something). The <variable> is the name of the object. The cycle number along with the variable name uniquely identifies the object. The <title> is the string given in the constructor of the object as title.

This picture shows a `TFile` with five objects in the top directory (`kObjA;1, kObjA;2, kObjB;1, kObjC;1 and kObjD;1`). `ObjA` is on file twice with two different cycle numbers. It also shows four objects in memory (`mObjE, mObjeF, mObjM, mObjL`). It also shows several subdirectories.



The Current Directory

If you have a ROOT session running, please quit and start fresh.

When you create a `TFile` object, it becomes the current directory. Therefore, the last file to be opened is always the current directory. To check your current directory you can type:

```
root[] gDirectory->pwd()
Rint:/
```

This means that the current directory is the ROOT session (`Rint`). When you create a file, and repeat the command you will see the file becomes the current directory.

```
root[] TFile f1("AFile1.root");
root[] gDirectory->pwd()
AFile1.root:/
```

If you create two files, the last becomes the current directory.

```
root[] TFile f2("AFile2.root");
root[] gDirectory->pwd()
AFile2.root:/
```

To switch back to the first file, or to switch to any file in general, you can use the `TDirectory::cd` method. The next command changes the current directory back to the first file.

```
root [] f1.cd();
root [] gDirectory->pwd()
AFile1.root:/
```

Note that even if you open the file in "READ" mode, it still becomes the current directory.

CINT also offers a shortcut for `gDirectory->pwd()` and `gDirectory->ls()`, you can type:

```
root [] .pwd
AFile1.root:/
root [] .ls
TFile**         AFile1.root
 TFile*         AFile1.root
```

To return to the home directory, the one we were in before we opened any files:

```
root [] gROOT->cd()
(unsigned char)1
root [] gROOT->pwd()
Rint:/
```

Objects in Memory and Objects on Disk

The `TFile::ls()` method has an option to list the objects on disk ("-d") or the objects in memory ("-m"). If no option is given it lists both, first the objects in memory, then the objects on disk. For example:

```
root [] TFile *f = new TFile("hsimple.root");
root [] gDirectory->ls("-m")
TFile**         hsimple.root
 TFile*         hsimple.root
```

Remember that ***`gDirectory`*** is the current directory and at this time is equivalent to "`f`". This correctly states that no objects are in memory. The next command lists the objects on disk in the current directory.

```
root [] gDirectory->ls("-d")
TFile**         hsimple.root
 TFile*         hsimple.root
  KEY: TH1F     hpx;1    This is the px distribution
  KEY: TH2F     hpxpy;1  py vs px
  KEY: TProfile hprof;1  Profile of pz versus px
  KEY: TNtuple  ntuple;1 Demo ntuple
```

To bring an object from disk into memory, we have to use it or "Get" it explicitly. When we use the object, CINT gets it for us. For example drawing `hprof` will read it from the file and create an object in memory. Here we draw the profile histogram, and then we list the contents.

```
root [] hprof->Draw()
<TCanvas::MakeDefCanvas>: created default TCanvas with name
c1
root [] f->ls()
TFile** hsimple.root
TFile* hsimple.root
OBJ: TProfile hprof Profile of pz versus px : 0
KEY: TH1F hpx;1 This is the px distribution
KEY: TH2F hpxpy;1 py vs px
KEY: TProfile hprof;1 Profile of pz versus px
KEY: TNtuple ntuple;1 Demo ntuple
```

We now see a new line that starts with OBJ. This means that an object of class `TProfile`, called `hprof` has been added in memory to this directory. This new `hprof` in memory is independent from the `hprof` on disk. If we make changes to the `hprof` in memory, they are not propagated to the `hprof` on disk. A new version of `hprof` will be saved once we call `Write`.

You may wonder why `hprof` is added to the objects in the current directory. `hprof` is of the class `TProfile` that inherits from `TH1D`, which inherits from `TH1`. `TH1` is the basic histogram. All histograms and trees are created in the current directory. The reference to "all histograms" includes objects of any class descending directly or indirectly from `TH1`. Hence, our `TProfile hprof` is created in the current directory `f`.

There was another side effect when we called the `TH1::Draw` method. CINT printed this statement:

```
<TCanvas::MakeDefCanvas>: created default TCanvas with name c1
```

It tells us that a `TCanvas` was created and it named it `c1`. This is where ROOT is being nice, and it creates a canvas for drawing the histogram if no canvas was named in the draw command, and if no active canvas exists.

The newly created canvas, however, is NOT listed in the contents of the current directory. Why is that? The canvas is not added to the current directory, because ONLY histograms and trees are added to the object list of the current directory. Actually, `TEventList` objects are also added to the current directory, but at this time, we don't have to worry about those.

If the canvas is not in the current directory then where is it? Because it is a canvas, it was added to the list of canvases. This list can be obtained by the command `gROOT->GetListOfCanvases()->ls()`. The `ls()` will print the contents of the list. In our list, we have one canvas called `c1`. It has a `TFrame`, a `TProfile`, a `TPaveStats`.

```
root [] gROOT->GetListOfCanvases()->ls()
Canvas Name=c1 Title=c1 Option=
 TCanvas fXlowNDC=0 fYlowNDC=0 fWNDC=1 fHNDC=1 Name= c1 Title= c1
Option=   TFrame  X1= -4.000000 Y1=0.000000 X2=4.000000 Y2=19.384882
  OBJ: TProfile hprof   Profile of pz versus px : 0
  TPaveText  X1= -4.900000 Y1=20.475282 X2=-0.950000 Y2=21.686837 title
```

TPaveStats X1= 2.800000 Y1=17.446395 X2=4.800000 Y2=21.323371 stats

Lets proceed with our example and draw one more histogram, and we see one more OBJ entry.

```
root [] hpx->Draw()
root [] f->ls()
TFile**         hsimple.root
 TFile*         hsimple.root
  OBJ: TProfile hprof  Profile of pz versus px : 0
  OBJ: TH1F     hpx    This is the px distribution : 0
  KEY: TH1F     hpx;1  This is the px distribution
  KEY: TH2F     hpxpy;1 py vs px
  KEY: TProfile hprof;1 Profile of pz versus px
  KEY: TNtuple  ntuple;1        Demo ntuple
```

`TFile::ls()` makes a loop over the list of objects in memory and another over the list of objects on disk. In both cases, it calls the `ls()` method of each object. The implementation of the `ls` method is specific to the class of the object, but since all of these objects are in a file, they are descendants of `TObject` and inherit the `TObject::ls()` implementation. The histogram classes are descendants of `TNamed` that in turn is a descent of `TObject`. In this case, `TNamed::ls()` is executed, and it prints the name of the class, and the name and title of the object.

Each directory keeps a list of its "in memory" objects. You can get this list by using `TDirectory::GetList`. To see the lists contents you need to call `Print()`.

```
root [] gDirectory->GetList()->Print()
TH1.Print Name= hprof, Entries= 10000, Total sum= 437.642
TH1.Print Name= hpx, Entries= 10000, Total sum= 10000
```

Since the file `f` is the current directory, this will yield the same result:

```
root [] f->GetList()->Print()
TH1.Print Name= hprof, Entries= 10000, Total sum= 437.642
TH1.Print Name= hpx, Entries= 10000, Total sum= 10000
```

Saving Histograms to Disk

At this time, the objects in memory (OBJ) are identical to the objects on disk (KEY). Let's change that by adding a fit to the `hpx` we have in memory.

```
root [] hpx->Fit("gaus")
```

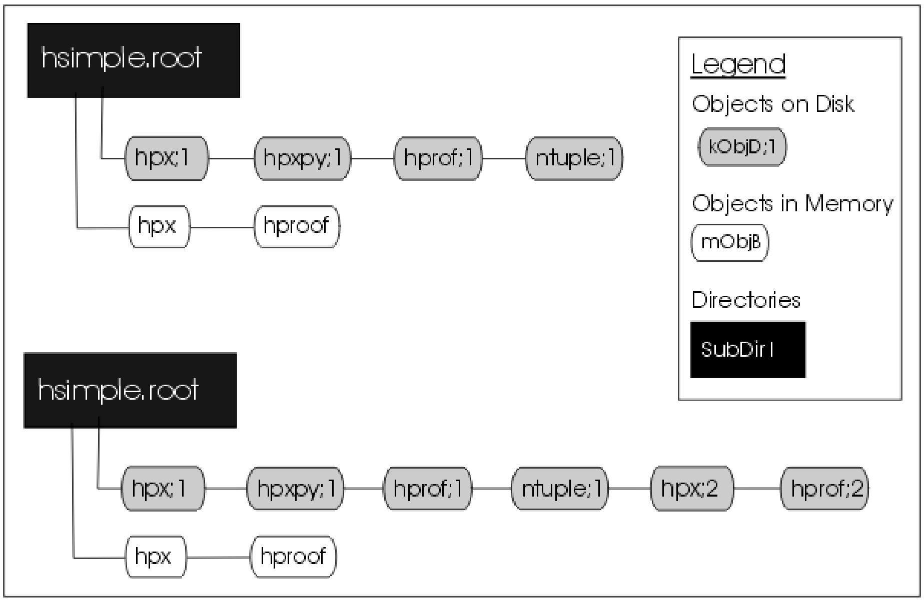
Now the `hpx` in memory is different from the histogram (`hpx`) on disk. The `hpx` in memory has a `TF1` (or a function) added to its structure.

Only one version of the object can be in memory, however, on disk we can store multiple versions of the object. The `TFile::Write` method will write the list of objects in the current directory to disk. It will add a new version of `hpx` and `hprof`.

```
root [] f->Write()
root [] f->ls()
TFile**         hsimple.root
 TFile*         hsimple.root
  OBJ: TProfile hprof  Profile of pz versus px : 0
  OBJ: TH1F     hpx    This is the px distribution : 0
  KEY: TH1F     hpx;2  This is the px distribution
  KEY: TH1F     hpx;1  This is the px distribution
  KEY: TH2F     hpxpy;1 py vs px
  KEY: TProfile hprof;2 Profile of pz versus px
  KEY: TProfile hprof;1 Profile of pz versus px
  KEY: TNtuple  ntuple;1        Demo ntuple
```

The `TFile::Write` method wrote the entire list of objects in the current directory to the file. You see that it added two new keys: `hpx;2` and `hprof;2` to the file. Unlike memory, a file is capable of storing multiple objects with the same name. Their cycle number, the number after the semicolon, differentiates objects on disk with the same name.

This picture shows the file before and after the call to `Write`.



If you wanted to save only `hpx` to the file, but not the entire list of objects, you could use the `TH1::Write` method of `hpx`:

```
root [] hpx->Write()
```

A call to `Write` without any parameters will call `GetName()` to find the name of the object and use it to create a key with the same name. You can specify a new name by giving it as a parameter to the `Write` method.

```
root [] hpx->Write("newName")
```

If you want to re-write the same object, with the same key, use the overwrite option.

```
root [] hpx->Write("", TObject::kOverwrite)
```

If you give a new name and use the `kOverwrite`, the object on disk with the matching name is overwritten if such an object exists. If not, a new object with the new name will be created.

```
root [] hpx->Write("newName", TObject::kOverwrite)
```

The `Write` method did not affect the objects in memory at all. However, if the file is closed, the directory is emptied and the objects on the list are deleted.

```
root [] f->Close()
root [] f->ls()
TFile**         hsimple.root
 TFile*         hsimple.root
```

In the code snipped above you can see that the directory is now empty. If you followed along so far, you can see that c1 which was displaying `hpx` is now blank. Furthermore, `hpx` no longer exists.

```
root [] hpx->Draw()
Error: No symbol hpx in current scope
```

This is important to remember, do not close the file until you are done with the objects or any attempt to reference the objects will fail.

Histograms and the Current Directory

When a histogram is created, it is added by default to the list of objects in the current directory. You can get the list of histograms in a directory and retrieve a pointer to a specific histogram.

```
TH1F *h = (TH1F*)gDirectory->Get("myHist");
```

or

```
TH1F *h = (TH1F*)gDirectory->GetList()->FindObject("myHist");
```

The method `TDirectory::GetList()` returns a `TList` of objects in the directory.

```
h->SetDirectory(newDir)
```

You can change the directory to which a histogram will be added with the `SetDirectory` method.

```
h->SetDirectory(0)
```

You can also remove a histogram from its directory. Once a histogram is removed from the directory, it will no longer be deleted when the directory is closed. It is now your responsibility to delete this histogram object once you are finished with it.

To change the default that automatically adds the histogram to the current directory, you can call the static function:

```
TH1::AddDirectory(kFALSE);
```

In this case, you will need to do all the bookkeeping for all the created histograms.

Saving Objects to Disk

In addition to histograms and trees, you can save any object in a ROOT file provided it inherits from `TObject`. To save a canvas to the ROOT file you can use `TCanvas::Write`.

```
root [] TFile *f = new TFile("hsimple.root", "UPDATE")
root [] hpx->Draw()
<TCanvas::MakeDefCanvas>: created default TCanvas with name
c1
root [] c1->Write()
root [] f->ls()
TFile**         hsimple.root
TFile*         hsimple.root
OBJ: TH1F     hpx    This is the px distribution : 0
  KEY: TH1F     hpx;2   This is the px distribution
  KEY: TH1F     hpx;1   This is the px distribution
  KEY: TH2F     hpxpy;1 py vs px
  KEY: TProfile hprof;2 Profile of pz versus px
  KEY: TProfile hprof;1 Profile of pz versus px
  KEY: TNtuple  ntuple;1        Demo ntuple
  KEY: TCanvas  c1;1    c1
```

Saving Collections to Disk

All collection classes inherit from `TCollection` (see Chapter on Collection Classes) and hence inherit the `TCollection::Write` method. When you call `TCollection::Write()` each objects in the container is written individually into its own key in the file.

To write all objects into one key you can specify the name of the key and use the `TObject::kSingleKey` option. For example:

```
root[] TList * list = new TList;
root[] TNamed * n1, * n2;
root[] n1 = new TNamed("name1", "title1");
root[] n2 = new TNamed("name2", "title2");
root[] list->Add(n1);
root[] list->Add(n2);
root[] list->Write("list", TObject::kSingleKey);
```

A TFile Object going Out of Scope

There is another important point to remember about `TFile::Close` and `TFile::Write`. When a variable is declared on the stack in a function such as in the code below, it will be deleted when it goes out of scope.

```
void foo() {
      TFile f("AFile.root", "RECREATE");
}
```

As soon as the function `foo` is finished executing, the variable `f` is deleted. When a `TFile` object is deleted an implicit call to `TFile::Close` is made. This will save the file to disk. However, it does not make a call to `Write`, which means that the object in memory will not be saved in the file.

You will need to make an explicit call to `TFile::Write()` to save the object in memory to file before the exit of the function.

```
void foo() {
      TFile f("AFile.root", "RECREATE");
      … stuff …
      f->Write();
}
```

To prevent an object in a function from being deleted when it goes out of scope, you can create it on the heap instead of on the stack. This will create a `TFile` object `f`, that is available on a global scope, and it will still be available when exiting the function.

```
void foo() {
      TFile *f = new TFile("AFile.root", "RECREATE");
}
```

Retrieving Objects from Disk

If you have a ROOT session running, please quit and start fresh.

We saw that multiple versions of an object with the same name can be in a ROOT file. In our example, we saved a second histogram `hpx` with a fit to the file, which resulted in two `hpx's` uniquely identified by the cycle number: `hpx;1` and `hpx;2`. The question is how do we retrieve the right version of `hpx`.

When opening the file and using `hpx`, CINT retrieves the one with the highest cycle number.

To read the `hpx;1` into memory, rather than the `hpx:2` we would get by default, we have to explicitly get it and assign it to a variable.

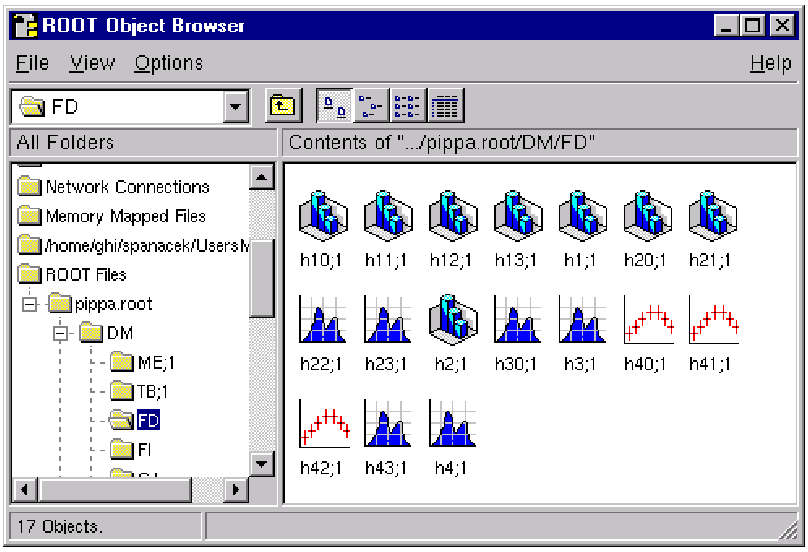
```
root [] TFile *f1 = new TFile("hsimple.root")
root [] TH1F *hpx1 = (TH1F*) f1->Get("hpx;1")
root [] hpx1->Draw()
```

Subdirectories and Navigation

The `TDirectory` class lets you organize its contents into subdirectories, and `TFile` being a descendent of `TDirectory` inherits this ability.

Here is an example of a ROOT file with multiple subdirectories as seen in the ROOT browser.

Creating Subdirectories



To add a subdirectory to a file use `Directory::mkdir`.

The example below opens the file for writing and creates a subdirectory called "Wed_03_29". Listing the contents of the file shows the new directory in the file and the `TDirectory` object in memory.

```
root [] TFile *f = new TFile("AFile.root","RECREATE")
root [] f->mkdir("Wed_03_29")
(class TDirectory*)0x1072b5c8
root [] f->ls()
TFile**          AFile.root
 TFile*          AFile.root
  TDirectory*            Wed_03_29        Wed_03_29
  KEY: TDirectory        Wed_03_29;1      Wed_03_29
```

Navigating to Subdirectories

We can change the current directory by navigating into the subdirectory, and after changing directory; we can see that ***`gDirectory`*** is now "Wed_03_29".

```
root [] f->cd("Wed_03_29")
root [] gDirectory->pwd()
AFile.root:/Wed_03_29
```

In addition to ***`gDirectory`*** we have ***`gFile`***, another global that points to the current file.
In our example, ***`gDirectory`*** points to the subdirectory, and ***`gFile`*** points to the file (i.e. the files' top directory).

```
root [] gFile->pwd()
AFile.root:/
```

To return to the file's top directory, use `cd()` without any arguments.

```
root [] f->cd()
AFile.root:/
```

Change to the subdirectory again, and create a histogram. It is added to the current directory, which is the subdirectory "Wed_03_29".

```
root [] f->cd("Wed_03_29")
root [] TH1F *histo=new TH1F("histo","histo",10,0, 10);
root [] gDirectory->ls()
TDirectory*             Wed_03_29       Wed_03_29
 OBJ: TH1F      histo   histo : 0
```

We write the file to save the histogram on disk, to show you how to retrieve it later.

```
root [] f->Write()
root [] gDirectory->ls()
TDirectory*             Wed_03_29       Wed_03_29
 OBJ: TH1F      histo   histo : 0
 KEY: TH1F      histo;1 histo
```

When retrieving an object from a subdirectory, you can navigate to the subdirectory first or give it the path name relative to the file. The read object is created in memory in the current directory.

In this first example, we get `histo` from the top directory and the object will be in the top directory.

```
root [] TH1 *h = (TH1*) f->Get("Wed_03_29/histo;1")
```

If file is written, a copy of `histo` will be in the top directory. This is an effective way to copy an object from one directory to another.

In contrast, in the code box below, `histo` will be in memory in the subdirectory because we changed the current directory.

```
root [] f->cd("Wed_03_29");
root [] TH1 *h = (TH1*) gDirectory->Get("histo;1")
```

Note that there is no warning if the retrieving was not successful. You need to explicitly check the value of h, and if it is null, the object could not be found. For example, if you did not give the path name the histogram cannot be found and 'h' is null:

```
root [] TH1 *h =(TH1*)gDirectory->Get("Wed_03_29/histo;1")
root [] h
(class TH1*)0x10767de0
root [] TH1 *h = (TH1*) gDirectory->Get("histo;1")
root [] h
(class TH1*)0x0
```

Removing Subdirectories

To remove a subdirectory you need to use `TDirectory::Delete`. There is no `TDirectory::rmdir`. The Delete method takes a string containing the variable name and cycle number as a parameter.

```
void Delete(const char *namecycle)
```

The `namecycle` string has the format `name;cycle`. Here are some rules to remember:

- `name =` * means all, but don't remove the subdirectories
- `cycle =` * means all cycles (memory and file)
- `cycle =` "" means apply to a memory object
- `cycle =` 9999 also means apply to a memory object
- `namecycle` = "" means the same as `namecycle` ="T*"
- `namecycle` = T* delete subdirectories

For example to delete a directory from a file, you must specify the directory cycle,

```
root [] f->Delete("Wed_03_29;1")
```

Some other examples of `namecycle` format are:

- `foo`: delete the object named `foo` from memory
- `foo;1`: delete the cycle 1 of the object named `foo` from the file
- `foo;*`: delete all cycles of `foo` from the file and also from memory
- `*;2`: delete all objects with cycle number 2 from the file
- `*;*`: `delete` all objects from memory and from the file
- `T*;*`: delete all objects from memory and from the file including all subdirectories

Streamers

To follow the discussion on streamers, you need to know what a simple data type is. A variable is of a simple data type if it cannot be decomposed into other types. Examples of simple data types are longs, shorts, floats, and chars. In contrast, a variable is of a composite data type if it can be decomposed. For example, classes, structures, and arrays are composite types. Simple types are also called primitive types, basic types, and CINT sometimes calls them fundamental types.

When we say, "writing an object to a file", we actually mean writing the current values of the data members. The most common way to do this is to decompose the object into its data members and write them to disk. The decomposition is the job of the streamer. Every class with ambitions to be stored in a file has a streamer that decomposes it and "streams" its members into a buffer.

To decompose the parent classes, the streamer calls the streamer of the parent classes. It moves up the inheritance tree until it reaches an ancestor without a parent.

To decompose the object data members it calls their streamer. They in turn move up their own inheritance tree and so forth.

The simple data members are written to the buffer directly. Eventually the buffer contains all simple data members of all the classes that make up this particular object.

A Streamer Example

The Event class is defined in $ROOTSYS/test/Event.h. If you have a chance, open the file now and follow along. Looking at the class definition, we find that indeed it inherits from TObject. Event has four integer data members, one float, an EventHeader object, a pointer to an array of track objects, and a pointer to a histogram object. Note that fEvtHdr is an object, where fTracks and fH are pointers to objects.

```
class Event : public TObject {

private:
   Int_t          fNtrack;
   Int_t          fNseg;
   Int_t          fNvertex;
   UInt_t         fFlag;
   Float_t        fTemperature;
   EventHeader    fEvtHdr;
   TClonesArray  *fTracks;
   TH1F          *fH;
…
```

The implementation of Event is in $ROOTSYS/test/Event.cxx. Open Event.cxx and locate the Event::Streamer method. The Streamer method takes a pointer to a TBuffer as a parameter, and first checks to see if this is a case of reading or writing the buffer. Let's look at the case of writing the buffer.

```
void Event::Streamer(TBuffer &R__b)
{
… //reading part
   } else { // writing part
      R__c = R__b.WriteVersion(Event::IsA(), kTRUE);
      TObject::Streamer(R__b);
      R__b << fNtrack;
      R__b << fNseg;
      R__b << fNvertex;
      R__b << fFlag;
      R__b << fTemperature;
      fEvtHdr.Streamer(R__b);
      fTracks->Streamer(R__b);
      fH->Streamer(R__b);
      R__b.SetByteCount(R__c, kTRUE);
   }
}
```

First, we see a call to TBuffer::WriteVersion.

```
R__c = R__b.WriteVersion(Event::IsA(), kTRUE);
```

There are two parameters. The first is a pointer to a TClass object that describes the Event class. The method call Event::IsA() returns this TClass pointer. The TClass object contains the full dictionary of the Event class. It has list to base classes, data members and methods.

The second parameter is a Boolean to calculate the byte count position. If it is set to kFALSE, it returns 0. If it is set to kTRUE, it returns the position in the file where the byte count is to be placed. The position is used later when setting the byte count with the SetByteCount method.

Class versioning is important and deserves a detailed discussion. It is covered a little later in the Schema Evolution section. For now, let's see how the object is decomposed.

A call to `TObject::Streamer` is made because it is the parent of `Event`. If `Event` were to inherit from multiple parents, its streamer would call each of the parent's `Streamer` method here.

```
TObject::Streamer(R__b);
```

Then each data member is added to the buffer. Simple data members are added directly.

```
R__b << fNtrack;
R__b << fNseg;
R__b << fNvertex;
R__b << fFlag;
R__b << fTemperature;
```

Object data members are added by calling their `Streamer`. The `Event` class has three object data members: an Event Header (`fEvtHdr`), an array of tracks (`fTracks`), and a histogram (`fH`).

```
fEvtHdr.Streamer(R__b);
fTracks->Streamer(R__b);
fH->Streamer(R__b);
```

Note the difference in the syntax of the method call with an object versus making the call with a pointer to an object. The `EventHeader fEvtHdr` is an object and its streamer is called with the "." operator:

```
fEvtHdr.Streamer(R__b);
```

The variables `fTracks` and `fH` are pointers to objects. Their streamer is called with the "->" operator as in:

```
fTracks->Streamer(R__b);
fH->Streamer(R__b);
```

The recursive nature of the streamers builds a buffer with only simple variables. The buffer will contain:

- Data members of all inherited classes
- Data members of the class itself
- Data members of its object data members

Byte Count

The last line in the streamer writes the byte count.

```
R__b.SetByteCount(R__c, kTRUE);
```

When ROOT reads an object and it cannot find its streamer, ROOT has no way of interpreting the bytes and reassemble the object. In this case, ROOT skips the object and reads the next object. Root can do this because it reads the byte count at the beginning of each object. Root skips ahead by the number of bytes in the byte count. This allows for graceful recovery when reading undefined objects. It guarantees that even if an object is not readable, subsequent objects will still be read.

The byte count is also used to check that the number of bytes read is the same as what was expected.

Let's look at how the byte count is managed in the streamer.

```
void Event::Streamer(TBuffer &R__b)
{
  // Stream an object of class Event.
  Uint_t R__s, R__c;

// reading part
  if (R__b.IsReading()) {
      Version_t R__v = R__b.ReadVersion(&R__s, &R__c);
            if (R__v) {}
            … < stream in all data members >
            R__b.CheckByteCount(R__s, R__c, Event::IsA());

// writing part
      } else {
         R__c = R__b.WriteVersion(Event::IsA(), kTRUE);
            … // stream out all data members
         R__b.SetByteCount(R__c, kTRUE);
      }
}
```

In the writing part, `WriteVersion` returns the offset where the byte count should be placed. The variable is `R__c` now contains the location just before the version number.

```
R__c = R__b.WriteVersion(Event::IsA(), kTRUE);
```

`SetByteCount` writes the byte count at the reserved location.

```
R__b.SetByteCount(R__c, kTRUE);
```

So now the file contains the number of bytes that were written for that object.

Now, let's look at the reading part. `ReadVersion` returns the location of the current position in the input buffer. This spot is the beginning of the object description and is returned in the variable `R__s`. The variable `R__c` now contains the number of bytes we expect the object to have.

```
Version_t R__v = R__b.ReadVersion(&R__s, &R__c);
```

After reading all data members, `CheckByteCount` is called to check if the current position in the buffer matches the expected position by adding the byte count to the starting position.

```
R__b.CheckByteCount(R__s, R__c, Event::IsA());
```

If there is no match, an error is printed and the input buffer is positioned according to the byte count. This allows the system to correctly read the next object in the stream without interruption.

Note that the byte count version of the streamer can read (old) files generated by the streamer without a byte count. When the file does not contain a byte count

ReadVersion returns 0 and the following CheckByteCount method ignores the check.

In addition, a standard streamer can read files with a byte count. In this case the byte count is skipped by the ReadVersion method.

Writing Objects

The Streamer decomposes the objects into data members and writes them to a buffer. It does not write the buffer to a file, it simply populates a buffer with bytes representing the object. This allows us to write the buffer to a file or do anything else we could do with the buffer. For example, we can write it to a socket to send it over the network. This is beyond the scope of this chapter, but it is worthwhile to emphasize the need and advantage of separating the creation of the buffer from its use. Let's look how a buffer is written to a file.

A class needs to inherit from TObject to be saved to disk because it needs the TObject::Write method to write itself to the file. However, a class that is a data member of another class does not have to inherit from TObject, it only has to have a streamer. EventHeader is an example of such a case.

The TObject::Write method does the following:

1. Creates a TKey object in the current directory
2. Creates a TBuffer object which is part of the newly created TKey
3. Fills the TBuffer with a call to the class::Streamer method
4. Creates a second buffer for compression, if needed
5. Reserves space by scanning the TFree list. At this point, the size of the buffer is known.
6. Writes the buffer to the file
7. Releases the TBuffer part of the key and returns a 60-byte key as a reference to what was written to disk.

In other words, the TObject::Write calls the Streamer method of the class to build the buffer. The buffer is in the key and the key is written to disk. Once written to disk the memory consumed by the buffer part is released. The key part of the TKey is kept and returned as a parameter. The key consumes only 60 bytes, where the buffer since it contains the object data can be very large.

Streamers Generated by rootcint

A streamer usually calls other streamers, the streamer of its parents and data members. This architecture depends on all objects having streamers, because eventually they will be called. To ensure that a class has a streamer, rootcint automatically creates one in the ClassDef macro which is defined in $ROOTSYS/include/RTypes.h. rootcint defines several methods for any class, and one of them is the streamer. The automatically generated streamer is complete and can be used as long as no customization is needed.

In our example, the Event class has a custom streamer that we just looked at. The EventHeader, Track, and HistogramManager classes (also defined in Event.h) have rootcint-generated streamers. They are in the file $ROOTSYS/test/EventDict.cxx.

Below is the automatically generated `EventHeader::Streamer` from `EventDict.cxx.`

Note: When you use `rootcint` to generate a dictionary, make sure you use a unique filename, because `rootcint` appends it to the name of static function (see `G__cpp_reset_tabableEventDict()` and `G__set_cpp_environmentEventDict () in EventDict.cxx`).

```
void EventHeader::Streamer(TBuffer &R__b)
{
   // Stream an object of class EventHeader.

   if (R__b.IsReading()) {
      Version_t R__v = R__b.ReadVersion(); if (R__v) { }
      R__b >> fEvtNum;
      R__b >> fRun;
      R__b >> fDate;
      } else {
      R__b.WriteVersion(EventHeader::IsA());
      R__b << fEvtNum;
      R__b << fRun;
      R__b << fDate;
      }
}
```

The `EventHeader` class has only simple data members, but if we add a histogram, an object data member, it still works. The resulting streamer looks like this.

```
void EventHeader::Streamer(TBuffer &R__b)
{
   // Stream an object of class EventHeader.
   if (R__b.IsReading()) {
      …
      R__b >> fH;
   } else {
         …
         R__b << (TObject*)fH;
   }
}
```

At first it looks like the pointer is streamed out, but that is not so. The ">>" and "<<" operators are overwritten to call `ReadObject` and `WriteObject` respectively.

OK, now we know we have a choice to let `rootcint` make a streamer for us or to write our own. How do we let CINT know when to generate one and when not?

The input to the `rootcint` command (in the `makefile`) is a list of classes in a `LinkDef.h` file. For example, the list of classes for `Event` are listed in `$ROOTSYS/test/EventLinkDef.h`. The "-" at the end of the class name tells `rootcint` not to generate a streamer. In the example, you can see the `Event` class is the only one for which `rootcint` is instructed not to generate a streamer.

```
#ifdef __CINT__

#pragma link off all globals;
#pragma link off all classes;
#pragma link off all functions;

#pragma link C++ class EventHeader;
#pragma link C++ class Event-;
#pragma link C++ class HistogramManager;
#pragma link C++ class Track;

#endif
```

In ROOT version 1 and 2, you can tell `rootcint` to add the byte count check when generating a streamer, you need to add a "+" after the name of the class in the `LinkDef.h` file. For example to add the byte count check to the `EventHeader` streamer, add a "+" to the `EventHeader` entry (also see rootcint: The CINT Dictionary Generator).

IMPORTANT NOTE: In ROOT Version 3, a "+" after the class name will tell `rootcint` to use the new I/O system. The byte count check is always added. See: How To Use the New I/O System.

```
#pragma link C++ class EventHeader+;
```

We strongly recommend adding the byte count check. In case of an error in schema evolution the byte count, check will allow you to locate the problem.

Starting with ROOT version 3, you can instruct your class to ignore the `TObject` streamer with the `MyClass::Class::IgnoreTObjectStreamer` method.

When the class `kIgnoreTObjectStreamer` bit is set (by calling the `IgnoreTObjectStreamer method)`, the automatically generated Streamer will not call `TObject::Streamer`, and the `TObject` part of the class is not streamed to the file. This is useful in case you do not use the `TObject` `fBits` and `fUniqueID` data members. You gain space on the file, and you do not loose functionality.

When you collect your class in a TClonesArray it bypasses the Streamer of your class and uses a more efficient internal mechanism to write your class to the file. If the objects you store in the `TClonesArray` are of the type `MyClass`, you can disable the default behavior of bypassing the call to `MyClass::Streamer` by executing the line below once in the program before writing the file:

```
MyClass::Class()->BypassStreamer(kFALSE);
```

Streamers and Arrays

When the streamer comes across a data member that is a pointer to a simple type, it assumes it is an array. Somehow, `rootcint` has to find how many elements are in the array to reserve enough space in the buffer, and write out the appropriate number of elements. This is done in the definition of the class. For example, if we wanted to add an array of floats to the Event class we would add the following lines in the Event class definition.

```
class Event : public TObject {

private:
   Int_t          fNtrack;
      …
      Int_t       fN;
      Float_t     *fNArray;               //[fN]
      …
```

The array fNArray is defined as a pointer of floats (Float_t is root's type for a float). Then a comment mark (//) , and the length of the array in square brackets. In general the syntax is:

```
<simple type>     *<name>     //[<length>]
```

The length needs to be an integer, and it needs to be a data member defined in the class ahead of its use. It can also be defined in a base class. The length can be an expression, as long as the result is an integer.

Now we know how to write our own streamers, but why would you have to do that? The answer to that question is the subject of the next section on Schema Evolution.

Schema Evolution

Schema evolution means we can use multiple versions of the same class. Somewhere in the software is a black box that takes care of mapping one version to another.

In the lifetime of a collaboration, the definition of a class is likely to change frequently. Not only can the class itself change, but any of its parent classes can also change. This makes the support for schema evolution necessary. To do so, ROOT uses class versions.

When a class is defined in ROOT, it must include the ClassDef macro as the last line in the header file inside the class definition. The syntax of that call is:

```
ClassDef (<ClassName>,<VersionNumber>)
```

The version number is what identifies this particular version of the class. The version number is written to the file in the streamer by the call TBuffer::WriteVersion. You, as the designer of the class, need to customize the streamer to write the appropriate data members for each version.

As an example, let's say our Event class has changed. It needs a new integer. We add the data member and bump the version number in the ClassDef to two:

```
class Event : public TObject {
private:
Int_t       fNewInt;
Int_t       fNtrack;
…
      ClassDef (Event,2)
}
```

To correctly read and write this second version of Event, we need to change the streamer to read fNewInt for all versions greater than version 1, but not expect it for version one. The streamer now looks like this:

```
void Event::Streamer(TBuffer &R__b)
{
      if (R__b.IsReading()) {
            Version_t R__v = R__b.ReadVersion();
            TObject::Streamer(R__b);
            // read the new data member for all versions
            // beyond the first one
            if (R__v > 1) {
              R__b >> fNewInt;
            }
            R__b >> fNtrack;
            …
      } else {
            R__b.WriteVersion(Event::IsA());
            TObject::Streamer(R__b);
            R__b << fNewInt;
      …
      }
}
```

In the writing part of the streamer, you will always want to write all members. This elegant and simple versioning mechanism allows your objects to evolve and be backward compatible.

Note that if you are declaring your own classes but are not interested in writing it to a file you can set the version number to zero and `rootcint` will generate an empty streamer.

The I/O System in ROOT Version 3

The version 3.0 of ROOT includes several enhancements in the I/O sub system, such as:

- A new Automatic Class Schema Evolution system.
- The `StreamerInfo` saved to ROOT files.
- A self-describing object format.
- Full support for STL.
- An automatic code generator from the class `StreamerInfo`.

The new system is compatible with the current one. To use it, one must specify an option "+" in the pragma statement of the `LinkDef.h` file. To explain this new facility, we will use a simple example illustrating how I/O is done with the current version and what can be gained by selecting the new option.

To start, we will use the standard ROOT example in `$ROOTSYS/test/Event.h`. The same example will be used to also explain the new system.

```
class Event : public TObject {

private:
   char           fType[20];
   Int_t          fNtrack;
   Int_t          fNseg;
   Int_t          fNvertex;
   UInt_t         fFlag;
   Float_t        fTemperature;
   EventHeader    fEvtHdr;
   TClonesArray  *fTracks;
   TH1F          *fH;
   Int_t          fMeasures[10];
   Float_t        fMatrix[4][4];
   Float_t       *fClosestDistance;   //[fNvertex]

   ClassDef(Event,1)  //Event structure
};
```

To write an instance of the class Event to a file, we can do:

```
TFile f("demo.root","new");
Event *event = new event();
event->Write("event0");
```

The statement "`event->Write("event0")`" writes the object to the file creating a key with name *"event0"*. The Write function creates a `TBuffer` object and serializes all the members of the Event object to this buffer by invoking the `Event::Streamer` function. The Streamer function is generated automatically by the preprocessor `rootcint`.

```
  rootcint -f EventDict.cxx -c Event.h EventLinkDef.h
```

where `EventLinkDef.h` contains the following statements:

```
  #pragma link off all globals;
  #pragma link off all classes;
  #pragma link off all functions;
  #pragma link C++ class Event;
```

The file `EventDict.cxx` contains among other things the function `Event::Streamer`.

```
void Event::Streamer(TBuffer &R__b)
{
   // Stream an object of class Event.

   UInt_t R__s, R__c;
   if (R__b.IsReading()) {
      Version_t R__v = R__b.ReadVersion(&R__s, &R__c); if
(R__v) { }
      TObject::Streamer(R__b);
      R__b.ReadStaticArray(fType);
      R__b >> fNtrack;
      R__b >> fNseg;
      R__b >> fNvertex;
      R__b >> fFlag;
      R__b >> fTemperature;
      fEvtHdr.Streamer(R__b);
      fTracks->Streamer(R__b);
      R__b >> fH;
      R__b.ReadStaticArray(fMeasures);
      R__b.ReadStaticArray((float*)fMatrix);
      delete []fClosestDistance;
      fClosestDistance = new Float_t[fNvertex];
      R__b.ReadFastArray(fClosestDistance,fNvertex);
      R__b.CheckByteCount(R__s, R__c, Event::IsA());
   } else {
      R__c = R__b.WriteVersion(Event::IsA(), kTRUE);
      TObject::Streamer(R__b);
      R__b.WriteArray(fType, 20);
      R__b << fNtrack;
      R__b << fNseg;
      R__b << fNvertex;
      R__b << fFlag;
      R__b << fTemperature;
      fEvtHdr.Streamer(R__b);
      fTracks->Streamer(R__b);
      R__b << (TObject*)fH;
      R__b.WriteArray(fMeasures, 10);
      R__b.WriteArray((float*)fMatrix, 16);
      R__b.WriteFastArray(fClosestDistance,fNvertex);
      R__b.SetByteCount(R__c, kTRUE);
   }
}
```

The Streamer function above illustrates most of the I/O facilities in ROOT version 2.25.

- The statement "`R__b << fNtrack`" writes the integer fNtrack to the buffer `R__b`, taking care of byte swapping if necessary.
- The statement "`fEvtHdr.Streamer(R__b)`" invokes the Streamer function `EventHeader::Streamer` of the internal object `fEvtHdr` that in turn takes care of streaming all its members, etc.
- The statement "`fTracks->Streamer(R__b)`" streams the object pointed by `fTracks`. In this particular case, `fTracks` points to a TClonesArray, a collection of Track objects. All the objects in the array are streamed to the buffer object `R__b`.
- The statement "`R__b << fH`" is a variant of the case above. Here we assume that the pointer `fH` may be 0. In this case a special code is written to the buffer. if `fH` is not null, `fH->Streamer` is called.

- A statement like "R__b.WriteArray(fMeasures, 10)" writes to the buffer the length of the array (10) of fMeasures followed by the 10 values of the array itself.
- The statement "R__b.WriteFastArray(fClosestDistance,fNvertex)" writes only the fNvertex values of the array fClosestDistance to the buffer. In this case fNvertex may be null. This statement assumes that the variable fNvertex had already been written to the buffer. rootcint knows that the array fClosestDistance has a length fNvertex from the string [fNvertex] in the comment field of the data member declaration.
- The statement "R__b.SetByteCount(R__c, kTRUE)" writes the total number of bytes written by this Streamer (including the bytes written by the called Streamers) into the word reserved at address R__c of the buffer, where R__c was returned by the call to the first function in the statement R__c = R__b.WriteVersion(Event::IsA(), kTRUE);

In a following session, to read the Event object from the file, one can do:

```
root[] TFile f("demo.root");
root[] Event *event = (Event*)f.Get("event0");
```

The TFile::Get function searches for the TKey key named "event0". Once the TKey object is found, the TKey::ReadObj function is called to de-serialize the Event object from the TKey buffer. TKey::ReadObj creates an instance of the Event class by calling its default constructor, then the Event::Streamer function is called. A short description of this operation is:

- Find object TKey *key with name "event0" in the list of keys of the file. The TKey object knows that it is an instance of an object of a class named "Event" at a position filePos in the file.
- TFile::Get calls key->ReadObj. The TKey::ReadObj creates a TBuffer object with a length sufficient to read the object from the file. The stream of bytes at filePos is read into the buffer.
- TKey::ReadObj creates an instance of Event by executing:
- TClass *cl = gROOT->GetClass(key->GetClassName());
- TObject *obj = cl->New();

The first statement gets a pointer to a TClass object that contains the full dictionary for the class specified in the key (here "Event"). The second statement creates a class object by calling its default constructor via the CINT interface.

- Using the newly created (but empty) object, TKey::ReadObj calls obj->Streamer.

The Read part of the Streamer function simply performs the inverse operation of write by reading from the buffer R__b and restoring the class members. The statement "R__b.CheckByteCount(R__s, R__c, Event::IsA())" checks that the read position in the buffer is correct by comparing its actual value with the position at the start of the Streamer plus the byte count. In case of a mismatch, the pointer is set to the start position plus the byte count.

Manual Class Schema Evolution

When a data member is added or removed from a class, the Streamer function must be modified by hand. ROOT assumes that the user has increased the class version number in the ClassDef statement and introduced the relevant test in the read part of the Streamer. The Streamer function must be moved from the file generated by `rootcint` to the class implementation file. Because the Streamer function generated by `rootcint` is not any more adequate, one must now instruct rootcint to not generate this function. This is done by adding the character "-" at the end of the class name in the `LinkDef` file:

```
#pragma link C++ class Event-;
```

For example, if a new version of the `Event` class above includes a new member: `"Int_t fNew;"` the `ClassDef` statement should be changed to `ClassDef(Event,2)` and the following lines added to the read part of the Streamer:

```
if (R__v > 1) {
   R__b >> fNew;
} else {
   fNew = 0;  // set to some default value
}
```

If, in the same new version 2 we remove the member `fH`, one has to add the following code to read the histogram object into some temporary object and delete it:

```
if (R__v) < 2 {
   TH1F *dummy = 0;
   R__b >> dummy;
   delete dummy;
}
```

The experience so far with manual schema evolution shows that it is easy to make an error and frequent mismatches between `Streamer` writers and readers are observed when the number of classes increases.

Automatic Class Schema Evolution

To reduce the number of problems caused by manual intervention in the Streamer functions, the new version of ROOT has a facility to automate it. To use this new facility, one must specify the "+" option in the `LinkDef` file:

```
#pragma link C++ class Event+;
```

The version id in the `ClassDef` statement must still be incremented by the user. In case the user forgets to increase this number, ROOT includes a class checksum algorithm that will issue a warning message in case one reads an object having the same class version than the current class but with a different definition. Instead of generating the style of Streamer function shown above, a shorter Streamer is generated. For example, in the case of the class `Event` above, the following code is generated:

```
void Event::Streamer(TBuffer &R__b)
{
   // Stream an object of class Event.

   if (R__b.IsReading()) {
      Event::Class()->ReadBuffer(R__b, this);
   } else {
      Event::Class()->WriteBuffer(R__b, this);
   }
}
```

All the I/O is now managed automatically by `TClass::WriteBuffer` and `TClass::ReadBuffer`. In turn these two functions invoke the services of a new class `TStreamerInfo` that is the real I/O manager of the new version of ROOT.

With this new scheme, one can change at will the class definition, for example:

- change the order of data members in the class
- add new data members
- remove members
- move a member to a base class or vice-versa
- change the type of members if they are basic types or pointers to basic types
- add or remove a base class

From ROOT version 3 onwards, it is possible:

- to read old files (back compatibility) like now.
- to read files written by a new version of ROOT with an old version of ROOT
- to read old versions of a class
- to read new versions of a class when using an old class

How To Use the New I/O System

We will distinguish the following cases:

Case A: You have your own Streamer function in your class implementation file. This also means that you have specified `MyClass-` in the `LinkDef.h` file.

- keep `MyClass-` unchanged
- Increment your class version id in `ClassDef` by 1, eg.
  `ClassDef(MyClass, 2)`
- Change your Streamer function in the following way: The old write block can be totally replaced by the new standard Write. The read block uses the new scheme for the new versions and the old code for the old versions.

```
void MyClass::Streamer(TBuffer &R__b)
{
   // Stream an object of class MyClass.

   if (R__b.IsReading()) {
      UInt_t R__s, R__c;
      Version_t R__v = R__b.ReadVersion(&R__s, &R__c);
      if (R__v > 1) {
        MyClass::Class()->ReadBuffer(R__b, this, R__v, R__s, R__c);
        return;
      }
//====process old versions before automatic schema evolution
      R__b >> xxxx;
      R__b >> .. etc
      R__b.CheckByteCount(R__s, R__c, MyClass::IsA());
//====end of old versions

   } else {
      MyClass::Class()->WriteBuffer(R__b,this);
   }
}
```

Case B: You use the automatic streamer in the dictionary file.

- Move the old Streamer from the file generated by `rootcint` to your class implementation file, then modified the Streamer function as in case A above.
- Increment your class version id in ClassDef by 1, for example `ClassDef(MyClass, 2)`
- Add option "-" in the pragma line of `LinkDef`.

Case C: You use the automatic streamer in the dictionary file and you already use the option "+" in the `LinkDef` file. If the old automatic Streamer does not contain any statement using the function `WriteArray`, you have nothing to do, except running `rootcint` again to regenerate the new form of the Streamer function, otherwise proceed like for case B.

Streamers with special additions

For some classes, it may be necessary to execute some code before or after the read or write blocks. For example after the execution of the read block, one can initialize some non persistent members.

Support for more C++ constructs in the class definition

The new version supports all the C++ cases that were supported by the old version. In addition, a data member can be;

- any **STL container** or **pointer to an STL container** (vector, list, deque, map, set, multimap, multiset.
- more cases involving pointers to objects or pointers to pointers as illustrated in the evolution of `Event.h` shown below.

```
class Event : public TObject {

private:
   enum      {kSize=10};
   char      fType[20];                // array of 20 chars
   Int_t     fTransient;               //! do not write this member to disk
   Int_t     fNtrack;                  // number of tracks
   Int_t     fNseg;                    // number of segments
   Int_t     fNvertex;                 // number of vertices
   Int_t     fMeasures[kSize];         // an array where dimension
                                       // is an enum
   UInt_t    fFlag;                    // bit pattern event flag
   Float_t   fMatrix[4][4];            // a two-dim array
   Float_t  *fClosestDistance;         //[fNvertex] pointer to an
                                       // array of floats of length
                                       // fNvertex

   Float_t          fTemperature;      // event temerature
   vector<int>      fVectorint;        // STL vector on ints
   vector<short>    fVectorshort;      // STL vector of shorts
   vector<double>   fVectorD[4];       // array of STL vectors
                                       // of doubles
   vector<TObject> *fVectorTobject;    // pointer to an STL vector
   vector<TNamed>  *fVectorTnamed[6];  // array of pointers to
                                       // STL vectors
   deque<TAttLine>       fDeque;       // STL deque
   list<const TObject*>  fVectorTobjectp;
                                       // STL list of pointers
                                       // to objects

   map<TNamed*,int>      fMapTNamedp;  // STL map
   map<TAxis*,int>      *fMapTAxisp;   // pointer to STL map
   set<TAxis*>           fSetTAxis;    // STL set
   set<TAxis*>          *fSetTAxisp;   // pointer to STL set

   multimap<TNamed*,int> fMultiMapTNamedp; // STL multimap
   multiset<TAxis*>     *fMultiSetTAxisp;  // pointer to STL multiset

   string   fString;          // C++ standard string
   string  *fStringp;         // pointer to standard C++ string
   TString *fTstringp;        // [fNvertex] array of TString
   TString  fNames[12];       // array of TString
   TAxis    fXaxis;           // example of class derived
                              // from TObject
   TAxis    fYaxis[3];        // array of objects
   TAxis   *fVaxis[3];        // pointer to an array of TAxis
   TAxis   *fPaxis;           //[fNvertex] pointer to an array
                              // of TAxis of length fNvertex
   TAxis  **fQaxis;           //[fNvertex] pointer to an array
                              // of pointers to TAxis objs.
   EventHeader  fEvtHdr;      // example of class not derived
                              // from TObject
   TClonesArray *fTracks;     //-> array of tracks
   TH1F         *fH;          //-> pointer to an histogram
```

- The character "`!`" as the first character of the comment field indicates a non persistent member. This is the case above for `fTransient`.
- In the comment field of `fClosestDistance, [fNvertex]` indicates an array of length `fNvertex`. The index must be an integer defined before this member in the class itself or one of its base classes.

- The string "->" in the comment field of the members `fH` and `fTracks` instructs the automatic Streamer that it can assume that the objects `fH` and `fTracks` are never null pointers and that `fH->Streamer` can be used instead of the more expansive form `R__b << fH`.

The StreamerInfo saved in the ROOT file

The `StreamerInfo` is a subset of the CINT class dictionary for persistent data members and base classes only.

All classes that have at least one object written to a file have their `StreamerInfo` saved to the file. Each file contains one record (a TKey object called `StreamerInfo`) describing the classes in the file. This `StreamerInfo` record is automatically written when a file is closed. Vice versa, when a file is connected, its `StreamerInfo` record is read in memory. One can see the classes `StreamerInfo` in a file with:

```
TFile f("demo.root");
f.ShowStreamerInfo();
```

The `TFile::ShowStreamerInfo` function prints a list of classes in the file and for each class a list of the data members with their description. When the `StreamerInfo` record is read in memory, the corresponding information is stored for each class into a linked list of `TStreamerInfo` objects. One can print the `StreamerInfo` for a class with:

```
gROOT->GetClass("Event")->GetStreamerInfo(classVersion)->ls();
```

if the argument `classVersion` is not specified, the `StreamerInfo` corresponding to the current class is shown. `StreamerInfo` corresponding to different class versions may exist in different files. When reading an object from a file, the system will use the `StreamerInfo` of the file to decode an object in the automatic Streamer. In this way, the system can support loops on files containing instances of a class generated with different versions of the class.

The `StreamerInfo` record in a file adds a small overhead of typically a few Kilobytes per file. In the current implementation, the `StreamerInfo` object is visible with functions such as `TFile::ls`. It is foreseen to hide this object from the list of keys in the final implementation.

Automatic code generation from the StreamerInfo in a file

By using the two following statements:

```
TFile f("demo.root");
f.MakeProject("src");
```

one can generate a subdirectory (here called src) containing a header file for each class in the file. By default, `TFile::MakeProject` creates a header file for each class unknown to the current executable module. It is also possible to automatically generate a shared lib and link it with the running executable with:

```
f.MakeProject("src","*","new++);
```

When using the "`new++`" option (one can also specify "`recreate++`" or "`update++`"), `TFile::MakeProject` generates a small script called **MAKE** and executes it. The **MAKE** script calls `rootcint` to generate the class dictionary for all classes in the src directory, compile this file, create a shared lib and link it. For each header file generated, the original information of the data member part of the class is rebuilt, including the comment fields of the members. This makes possible the reading of any old ROOT file even when the code of the original classes is not available anymore. This facility is in particular useful to browse or analyze data in ROOT trees.

Currently `TFile::MakeProject` generates C++ code only. However, it would be trivial to extend this function to generate Java code instead.

Accessing ROOT Files Remotely via a rootd

Reading and writing ROOT files over the net can be done by creating a `TNetFile` object instead of a `TFile` object. Since the `TNetFile` class inherits from the `TFile` class, it has exactly the same interface and behavior. The only difference is that it reads and writes to a remote rootd daemon.

TNetFile URL

`TNetFile` file names are in standard URL format with protocol "`root`". The following are valid `TNetFile` URL's:

```
root://hpsalo/files/aap.root
root://hpbrun.cern.ch/root/hsimple.root
root://pcna49a:5151/~na49/data/run821.root
root://pcna49d.cern.ch:5050//v1/data/run810.root
```

The only difference with the well-known httpd URL's is that the root of the remote file tree is the remote user's home directory. Therefore an absolute pathname requires a `//` after the host or port (as shown in the last example above). Further the expansion of the standard shell characters, like `~, $, ..,` etc. is handled as expected. The default port on which the remote `rootd` listens is 1094 and this default port is assumed by `TNetFile` (actually by `TUrl` which is used by `TNetFile`). The port number has been allocated by the IANA and is reserved for ROOT.

Remote Authentication

Connecting to a `rootd` daemon requires a remote user id and password. `TNetFile` supports three ways for you to provide your login information:

1. Setting it globally via the static `TNetFile` functions `TNetFile::SetUser()` and `TNetFile::SetPasswd()`
2. Via the `~/.netrc` file (same format and file as used by ftp)
3. Via command line prompt

The different methods will be tried in the order given above. On machines with AFS, `rootd` will obtain an AFS token.

A Simple Session

```
root [] TFile *f1 = TFile::Open("local/file.root", "update")
root [] TFile *f2 =
TFile::Open("root://pcna49a.cern.ch/data/file.root", "new")
Name (pcna49a:rdm):
Password:
root [] TFile *f3 =
TFile::Open("http://root.cern.ch/~rdm/hsimple.root")
root [] f3.ls()
TWebFile** http://root.cern.ch/~rdm/hsimple.root
TWebFile* http://root.cern.ch/~rdm/hsimple.root
KEY: TH1F hpx;1 This is the px distribution
KEY: TH2F hpxpy;1 py vs px
KEY: TProfile hprof;1 Profile of pz versus px
KEY: TNtuple ntuple;1 Demo ntuple
root [] hpx.Draw()
```

The rootd Daemon

The `rootd` daemon works with the `TNetFile` class. It allows remote access to ROOT database files in read or read/write mode. The `rootd` daemon can be found in the directory `$ROOTSYS/bin`. It can be started either via `inetd` or by hand from the command line (no need to be super user). Its performance is comparable with NFS but while NFS requires all kind of system permissions to setup, `rootd` can be started by any user. The simplest way to start `rootd` is by starting it from the command line while being logged in to the remote machine. Once started `rootd` goes immediately in the background (no need for the `&`) and you can log out from the remote node. The only argument required is the port number (1094) on which your private `rootd` will listen. Using `TNetFile` you can now read and write files on the remote machine.

For example:

```
hpsalo [] telnet fsgi02.fnal.gov
login: minuser
Password:
<fsgi02> rootd -p 1094
<fsgi02> exit
hpsalo [] root
root [] TFile *f =
TFile::Open("root://fsgi02.fnal.gov:1094/file.root","new")
Name (fsgi02.fnal.gov:rdm): minuser
Password:
root [] f.ls()
```

In the above example, `rootd` runs on the remote node under user id `minuser` and listens to port 1094. When creating a `TNetFile` object you have to specify the same port number 1094and use `minuser` (and corresponding password) as login id. When `rootd` is started in this way, you can only login with the user id under which `rootd` was started on the remote machine. However, you can make many connections since the original `rootd` will fork (spawn) a new `rootd` that will service the requests from the `TNetFile`. The original `rootd` keeps listening on the specified port for other connections. Each time a `TNetFile` makes a connection; it gets a new private `rootd` that will handle its requests. At the end of a ROOT, session when all `TNetFiles` are closed only the original `rootd` will stay alive ready to service future `TNetFiles`.

Starting rootd via inetd

If you expect to often connect via `TNetFile` to a remote machine, it is more efficient to install `rootd` as a service of the `inetd` super daemon. In this way, it is not necessary for each user to run a private `rootd`. However, this requires a one-time modification of two system files (and super user privileges to do so). Add to `/etc/services` the line:

```
rootd     1094/tcp
```

To `/etc/inetd.conf` the line:

```
rootd stream tcp nowait root /usr/local/root/bin/rootd rootd
-i
```

After these changes force `inetd` to reread, its config file with "`kill -HUP <pid inetd>`".

When setup in this way it is not necessary to specify a port number in the URL given to `TNetFile`. `TNetFile` assumes the default port to be 1094 as specified above in the `/etc/services` file.

Command Line Arguments for `rootd`

`rootd` support the following arguments:

```
-i            says we are started by inetd
-p port#      specifies port number to listen on
-d level      level of debug info written to syslogd
              0 = no debug (default)
              1 = minimum
              2 = medium
              3 = maximum
```

Reading ROOT Files via Apache Web Server

By adding one ROOT specific module to your Apache web server, you can distribute ROOT files to any ROOT user. There is no longer a need to send your files via FTP and risking (out of date) histograms or other objects. Your latest up-to-date results are always accessible to all your colleagues.

To access ROOT files via a web server, create a `TWebFile` object instead of a `TFile` object with a standard URL as file name. For example:

```
root [] TWebFile f("http://root.cern.ch/~rdm/hsimple.root")
root [] f.ls()
TWebFile** http://root.cern.ch/~rdm/hsimple.root
TWebFile* http://root.cern.ch/~rdm/hsimple.root
KEY: TH1F hpx;1 This is the px distribution
KEY: TH2F hpxpy;1 py vs px
KEY: TProfile hprof;1 Profile of pz versus px
KEY: TNtuple ntuple;1 Demo ntuple
root [] hpx.Draw()
```

Since `TWebFile` inherits from `TFile` all `TFile` operations work as expected. However, due to the nature of a web server a `TWebFile` is a read-only file. A `TWebFile` is ideally suited to read relatively small objects (like histograms or other data analysis results). Although possible, you don't want to analyze large `TTree's` via a `TWebFile`.

Here follows a step-by-step recipe for making your Apache 1.1 or 1.2 web server ROOT aware:

1. Go to your Apache source directory and add the file ftp://root.cern.ch/root/mod_root.c or ftp://root.cern.ch/root/mod_root133.c when your Apache server is > 1.2 (rename the file `mod_root.c`).
2. Add to the end of the `Configuration` file the line:
   `Module root_module mod_root.o`
3. Run the `Configure` script
4. Type `make`
5. Copy the new `httpd` to its expected place
6. Go to the `conf` directory and add at the end of the `srm.conf` file the line:
   `AddHandler root-action root`
7. Restart the `httpd` server

Using the General TFile::Open() Function

To make life simple we provide a general function to open any type of file (except shared memory files of class `TMapFile`). This functionality is provided by the static `TFile::Open()` function:

```
TFile *TFile::Open(const Text_t *name, Option_t *option="",
      const Text_t *title="",
```

Depending on the `name` argument, the function returns a `TFile`, a `TNetFile` or a `TWebFile` object. In case a `TNetFile` URL specifies a local file, a `TFile` object will be returned (and of course no login information is needed). The arguments of the `Open()` function are the same as the ones for the `TFile` constructor.

10 Trees

In this chapter, we discuss the `TTree` class and its descendent class `TNtuple`. First, we go through an example and show you how to analyze data in a `TNtuple` using ROOT's graphical user interface, the tree viewer. Then we explain how to build a `TTree` and add branches, and finally how to use a `TTree` programmatically in data analysis.

Why should you Use a Tree?

In the chapter on Input/Output, we saw how objects can be saved in ROOT files. In case you want to save large quantities of the same objects, ROOT has designed the `TTree` and `TNtuple` classes specifically for that purpose. The `TTree` class is optimized to reduce disk space and enhance access speed. The `TNtuple` is a `TTree` that is limited to only hold floating-point numbers; a `TTree` on the other hand can hold all kind of data, such as objects or arrays in addition to all the simple types.

When using a `TTree`, we fill its branch buffers with leaf data and the buffers are written to file when it is full. Branches, buffers, and leafs, are explained a little later in this chapter, but for now, it is important to realize that not each object is written individually, but rather collected and written a bunch at a time.

This is where the `TTree` takes advantage of compression and will produce a much smaller file than if the objects were written individually. Since the unit to be compressed is a buffer, and the `TTree` contains many same-class objects, the header of the objects can be compressed. The `TTree` already reduces the header of each object, but it still contains the class name. Using compression, the class name of each same-class object has a good chance of being compressed, since the compression algorithm recognizes the bit pattern representing the class name. Using a `TTree` and compression the header is reduced to about 4 bytes compared to the original 60 bytes. However, if compression is turned off, you will not see these large savings.

The `TTree` is also used to optimize the data access. A tree uses a hierarchy of branches, and each branch can be read independently from any other branch. Now, assume that `Px` and `Py` are data members of the event, and we would like to compute $Px^2 + Py^2$ for every event and histogram the result. If we had saved the million events without a `TTree` we would have to: 1) read each event in its entirety into memory, 2) extract the `Px` and `Py` from the event, 3) compute the sum of the squares, and 4) fill a histogram. We would have to do that a million times! This is very time consuming, and we really do not need to read the entire event, every time. All we need are two little data members (`Px` and `Py`). On the other hand, if we use a tree with one branch containing `Px` and another branch containing `Py`, we can read all values of `Px` and Py by only reading the Px and Py branches. This makes the use of the TTree very attractive.

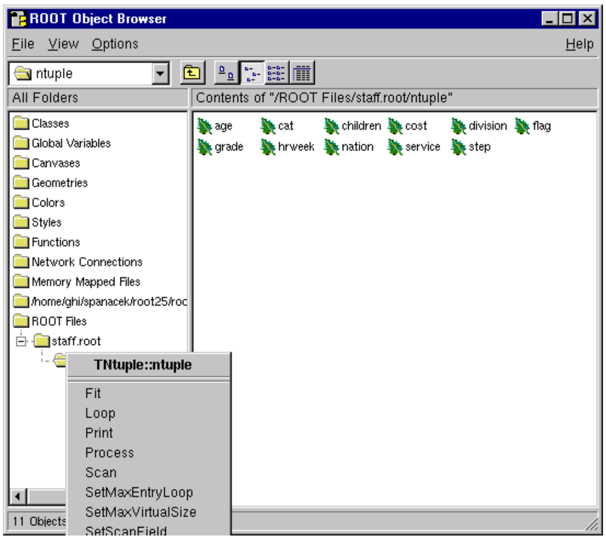
A TNtuple Example

Here is an example, a script that builds a TNtuple from an ASCII file containing statistics about the staff at CERN. This script, staff.C and its input file staff.dat are in the $ROOTSYS/tutorials.

The script declares a structured called staff_t, which holds several floating-point numbers each representing the relevant attribute of a staff member. It opens the ASCII file, creates a ROOT file and a TNtuple. The TNtuple constructor names the columns to be filled. It then reads the data from the ACSII file into the staff_t structure and fills the ntuple by giving it the address of the staff structure. The ASCII file is closed, and the ROOT file is written to disk saving the ntuple. Remember, trees and histograms are created in the current directory, which is the file in our example. Hence an f->Write() saves the ntuple it being a child class of a tree.

```
{
   gROOT->Reset();
   struct staff_t {
                Float_t cat;
                Float_t division;
                Float_t flag;
                Float_t age;
                Float_t service;
                Float_t children;
                Float_t grade;
                Float_t step;
                Float_t nation;
                Float_t hrweek;
                Float_t cost;
    };
   staff_t staff
   FILE *fp = fopen("staff.dat","r");
   char line[81];

   TFile *f = new TFile("staff.root","RECREATE");
   TNtuple *ntuple = new TNtuple("ntuple","staff data from ascii file",
"cat:division:flag:age:service:children:grade:step:nation:hrweek:cost");

   while (fgets(&line,80,fp)) {
      sscanf(&line[0] ,"%f%f%f%f",
             &staff.cat,&staff.division,&staff.flag,&staff.age);
      sscanf(&line[17],"%f%f%f%f",
             &staff.service,&staff.children,&staff.grade,&staff.step);
      sscanf(&line[33],"%f%f%f", &staff.nation,&staff.hrweek,&staff.cost);

      ntuple->Fill(&staff.cat);
   }
   ntuple->Print();

   fclose(fp);
   f->Write();
}
```

The Tree Viewer

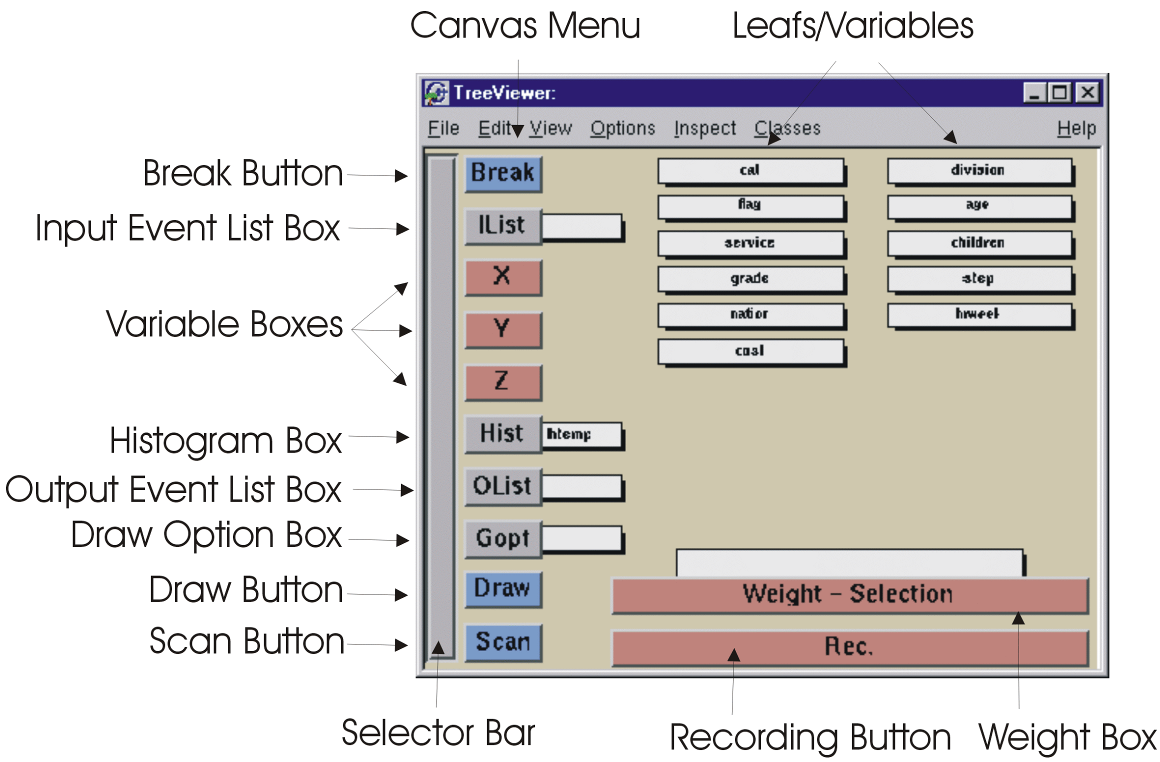


You will have a chance to read in much detail how to create a tree, but for now let's see what we can do with the tree viewer. Display an object browser and click into it until the ntuple becomes visible. Now click on the ntuple and select Start Viewer. This pictures shows the ntuple created in `staff.C`. You can see a leaf for each of the floating-point numbers.

Alternatively, you can call the `TTree::StartViewer` method from the command line.

```
root[] ntuple->StartViewer()
```

Here is what the tree viewer looks like.

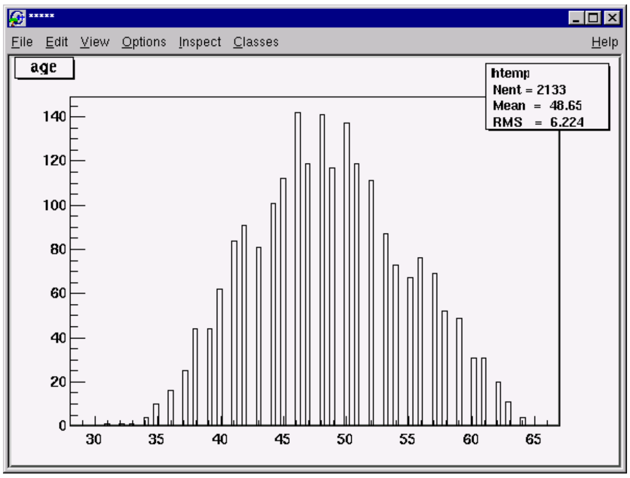


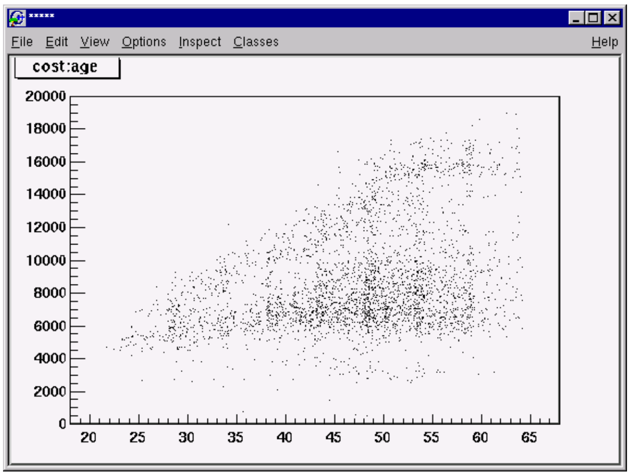
Here is an explanation of the buttons:

Boxes/ Buttons	It's purpose is …
Draw Button	To draw the active variable(s) that are placed in the X, Y, Z buttons
Scan Button	To scan the tree rather than draw it.
Break Button	To interrupt the current draw command
OList Box	To create a new `TEventList` using the current selection
IList Box	To activate a `TEventList` as an input selection
Hist Box	To define the histogram (default = `htemp`)
Gopt Box	To specify graphic options
X Box	To select the X variable
Y Box	To select the Y variable
Z Box	To select the Z variable
Weight-Selection Box	To select the weight/Selection expression
REC Button	To record the command in the history file

In addition, the vertical slider on the far left hand side can be used to select the minimum and maximum of an event range.

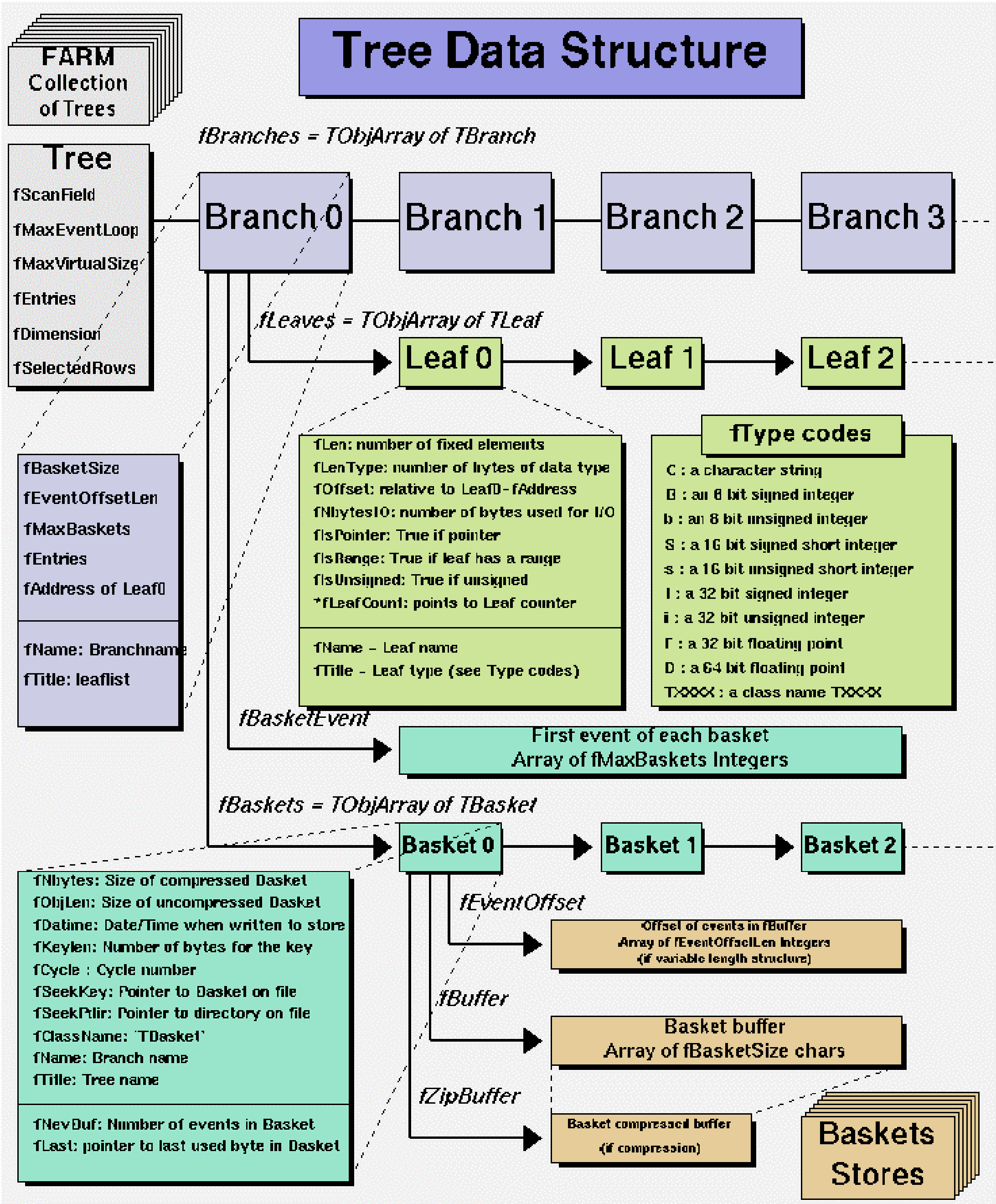
To draw a variable, just double click on it in the viewer. The histogram below shows the distribution of the age. To draw two variables, drag and drop one into the X box and the other into the Y box. In our example, we plotted cost vs. age in a scatter plot.





Creating and Saving Trees

To create a `TTree` we use its constructor. Then we design our data layout and add the branches.



Branches

By now, you probably guessed that the class for a branch is called `TBranch`. The organization of branches allows the designer to optimize the data for the anticipated use.

If two variables are independent, and the designer knows the variables will not be used together, she would place them on separate branches. If, however, the variables are related, such as the coordinates of a point, it is most efficient to create one branch with both coordinates on it. A variable on a `TBranch` is called a leaf (yes - `TLeaf`).

Another point to keep in mind when designing trees is the branches of the same `TTree` can be written to separate files.

To add a `TBranch` to a `TTree` we call the `TTree::Branch()` method. Note that we DO NOT use the `TBranch` constructor.

The `TTree::Branch` method has three signatures, one for each type. The branch type differs by what is stored in them. A branch can hold an entire object, a list of simple variables, or an array of objects. Let's see an example of each.

To follow along you will need the shared library `libEvent.so`. First, check if it is in `$ROOTSYS/test`. If it is, copy it to your own area. If it is not there, you have to build it.

Adding a TBranch to hold an Object

To write a branch to hold an event object, we need to load the definition of the `Event` class, which is in `$ROOTSYS/test/libEvent.so`.

```
root [] .L libEvent.so
```

First, we need to open a file and create a tree.

```
root [] TFile *f = new TFile("AFile.root", "RECREATE")
root [] TTree *tree = new TTree("T","A Root Tree")
```

We need to create a pointer to an `Event` object that will be used as a reference in the `TTree::Branch` method. Then we create a branch with the `TTree::Branch` method.

```
root[] Event *event = new Event()
root[] tree->Branch("EventBranch","Event", &event, 64000,1)
```

To add a branch to hold an object we use the signature above. The first parameter is the name of the branch. The second parameter is the name of the class of the object to be stored. The third parameter is the address of a pointer to the object to be stored.

Note that it is an address of a pointer to the object, not just a pointer to the object.

Keep in mind that the object needs to be a descendent of `TObject` to be written on a branch correctly.

The fourth parameter is the buffer size and is by default 32000.

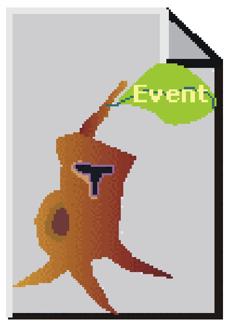
The last parameter is the split-level, which is the topic of the next section.

Static class members are not part of an object and thus not written with the object. You could store them separately by collecting these values in a special "status" object or, if they make sense for each object, make them normal data members.

Setting the Split-level

The split-level can be either one or zero, and the default is one. With the split-level of one, the object is split into a branch for each data member. The tree will look like the one on the left. It has a branch for each data member. Each branch has one leaf for the data member. The split is recursive for one level, which means if a data member is an object, it is also be split.

If the split-level is set to zero, the whole object is written in its entirety to one branch. The `TTree` will look like the one on the right, with one branch and one leaf holding the entire event object. When viewing a non-split branch in the tree viewer, the data members are not visible. Only the `Event` leaf will show.



A tree that is split

A tree that is not split

Rules about Splitting

When splitting a branch, variables of different types are handled differently. Here are the rules that apply:

- If a data member is a basic type, it becomes one branch of class `TBranch`.
- A data member can be an array of basic types (`e.g. fTable[12]`). In this case, one single branch is created for the array.
- If a data member is an object of a class derived from `TObject`, the data members of this object are also split into branches (one level only). This is, for example the case for the data member `fEvtHdr`. However objects of the classes `TArrayX` are not supported.
- If a data member is pointer to an object, a special branch of type `TBranchObject` is created. This is the case in our example for the data member `fH`, a pointer to a histogram. The `fH` branch will be filled by calling the class `Streamer` function to serialize this object into the branch buffer.
- In split mode, a data member cannot be a pointer to an array of basic types. A variable size array must be encapsulated inside another object derived from `TObject`. Below is an example of the syntax:

```
class A : public TObject
{
   B *b; // include the variable length array
}

class B : public TObject
{
   Int_t   n;     //length of the array bytes
   Byte_t *bytes; //[n] array with variable num. of entries
}
```

- In split mode, a data member cannot be a `TString` or an array of chars.
- In split mode, a data member cannot be a C structure.
- In split mode, a data member cannot be an array of objects.
- If a data member is a non-ROOT container (e.g. STL), you must implement the `Streamer` function for this class. It is our intention to modify `rootcint` to generate automatically the code to support STL containers.
- If a data member is a pointer to a `TClonesArray` object, one super branch of class `TBranchClones` is created. In our example, this is the case for the data member `fTracks`. This super branch will have a buffer where to store the number of objects in the array. This super branch has the name of the data member. ROOT will also automatically generate additional branches, one branch for each data member of the class referenced by the array (Track in the example). Note that the data members of this class must be basic types only or arrays of basic types (e.g. `fErrors[9]`). Data members of this class cannot be pointers.
- In split mode, a data member cannot be a `TClonesArray`. Only pointers to `TClonesArray` are accepted.

Note that splitting a branch can quickly generate many branches. Each branch has its own buffer in memory. In case of many branches (say more than 100), you should adapt the buffer size accordingly. A recommended buffer size is 32000 bytes if you have less than 50 branches. Around 16000 bytes if you have less than 100 branches and 4000 bytes if you have more than 500 branches. These numbers should be OK for existing computers with memory size ranging from 32MB to 256MB. If you have more memory, you should specify larger buffer sizes. However, in this case, do not forget that your file might be used on another machine with a smaller memory configuration.

When to Split a Branch

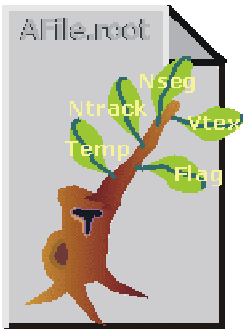
As a designer, you need to decide what split-level to use. These are some points to help you decide.

- A <u>split</u> object is useful when the data members are to be used independently. A separate branch will allow the user of this tree to read selective branches.
- A <u>split</u> object avoids a dependency on the class definition. If the object is split, only the primitive data types are used in the tree. This allows reading the class members without having the definition of the class. This is especially important for the longevity of the data, since over time the definition of the class may change or become unavailable.
- A single branch, i.e. <u>not splitting</u> the object, is useful when the tree is used to process a subset of entries.
- When an object is <u>not split</u>, the data members of the object are not visible in the browser. The data members are not accessible from the

object browser or tree viewer. To make the data members "browse-able", the object must be split.

- ROOT does not support splitting an object that has pointers as data members. Therefore, for objects containing pointers as data members the split-level needs to be 0.

Adding a Branch to hold a List of Variables



Sometimes, the data we want to save is a list of simple variables, such as integers or floats. In this case, we use the following `TTree::Branch` signature:

```
tree->Branch ("Ev_Branch",&event,
"temp/F:ntrack/I:nseg:nvtex:flag/i
");
```

The first parameter is the branch name. The second parameter is the address of the first variable in the leaf list, and the third parameter is the description of the leaf list. Let's look at the second and third parameter a little closer.

The second parameter is the address from which the first variable is to be read. In the code above, “event” is a structure with one float and three integers and one unsigned integer.

You should not assume that the compiler would align the elements of a structure without gaps. To avoid an alignment problem, we recommend specifying the largest variables first. If your structure cannot be rearranged, you will need to create one branch for each element of the structure.

The leaf name is NOT used to pick the variable out of the structure, but is only used the name for the leaf. This means that the list of variables needs to be in a structure in the order described in the third parameter.

This third parameter is a string describing the leaf list. Each leaf has a name and a type separated by a "/" and it is separated from the next leaf by a ":".

```
<Variable>/<type>:<Variable>/<type>
```

The example on the next line has two leafs: a floating-point number called `temp` and an integer named `ntrack`.

```
" temp/F:ntrack/I: "
```

The type can be omitted and if no type is given, the same type as the previous variable is assumed. This leaf list has three integers called `ntrack`, `nseg`, and `nvtex`.

```
"ntrack/I:nseg:nvtex"
```

There is one more rule: when no type is given for the very first leaf, it becomes a `float` (F). This leaf list has three floats called `temp`, `mass`, and `px`.

```
"temp:mass:px"
```

The symbols used for the type are:

C: a character string terminated by the 0 character.
B: an 8 bit signed integer.

b: an 8 bit unsigned integer.
S: a 16 bit signed integer.
s: a 16 bit unsigned integer.
I: a 32 bit signed integer.
i: a 32 bit unsigned integer.
F: a 32 bit floating point.
D: a 64 bit floating point.

The type is used for a byte count to decide how much space to allocate. The variable written is simply the block of bytes starting at the starting address given in the second parameter. It may or may not match the leaf list depending on whether or not the programmer is being careful when choosing the leaf address, name, and type.

By default, a variable will be copied with the number of bytes specified in the type descriptor symbol. However, if the type consists of two characters, the number specifies the number of bytes to be used when copying the variable to the output buffer. The line below describes `ntrack` to be written as a 16-bit integer (rather than a 32-bit integer).

```
"ntrack/I2"
```

With this Branch method, you can also add a leaf that holds an entire array of variables. To add an array of floats use the `f[n]` notation when describing the leaf.

```
Float_t  f[10];
```

tree->Branch("fBranch",&f,"**f[10]/F**");

You can also add an array of variable length:

```
{
   TFile *f = new TFile("peter.root","recreate");
   Int_t nPhot;
   Float_t E[500];

   TTree* nEmcPhotons = new TTree("nEmcPhotons","EMC Photons");
   nEmcPhotons->Branch("nPhot",&nPhot,"nPhot/I");
   nEmcPhotons->Branch("E",E,"E[nPhot]/F");
```

Adding a Branch to hold a TClonesArray

ROOT has two classes to manage arrays of objects. The `TObjArray` that can manage objects of different classes, and the `TClonesArray` that specializes in managing objects of the same class (hence the name Clones Array). `TClonesArray` takes advantage of the constant size of each element when adding the elements to the array. Instead of allocating memory for each new object as it is added, it reuses the memory. Here is an example of the time a `TClonesArray` can save over a `TObjArray`.

We have 100,000 events, and each has 10,000 tracks, which gives 1,000,000,000 tracks. If we use a `TObjArray` for the tracks, we implicitly make a call to new and a corresponding call to delete for each track. The time it takes to make a pair of new/delete calls is about 70 μs (10^{-6}). If we multiply the number of tracks by 70 μs, (1,000,000,000 * 70 * 10^{-6}) we calculate that the time allocating and freeing memory is about 19 hours. This is the chunk of time saved when a `TClonesArray` is used rather than a

TObjArray. If you don't want to wait 19 hours for your tracks (or equivalent objects), be sure to use a TClonesArray for same-class objects arrays.

ROOT has a Branch method that lets you put a TClonesArray (not a TObjArray) on a branch. If you need to use a TObjectArray you can use the TTree::Branch method for adding an object.

The syntax for a TClonesArray branch is:

```
tree->Branch( "Track_B",&Track,64000,1)
```

The first parameter is again the branch name. The second parameter is the address of a pointer to the TClonesArray. Note that this is again the address of a pointer to the array, not just a pointer to the array. The third parameter is the branch buffer size, which defaults to 32000.

The last parameter is the split-level. The split-level is by default one and it will split the object into one sub-branch for each data member. The tree will look like the one in the cartoon. If the split-level is set to zero, the object in the array will be written as one leaf. This is the same principle as discussed above when adding a branch with an object (see setting the split level).

Branches with TClonesArrays have the following advantages compared to the other two branch types.

- It minimizes the number of objects created/destroyed, which means faster access and memory savings.
- Data members of the same type are consecutive in the buffer, which optimizes the compression algorithm, and will result in a smaller tree.
- Array processing notation becomes possible when reading the tree data.

Note that the data members of the object in the array can only be basic types. The object cannot be saved correctly if it contains pointer data members.

Identical Branch Names

When a top-level object (say event), has two data members of the same class the sub branches end up with identical names. To distinguish the sub branch we must associate them with the master branch by including a "." (dot) at the end of the master branch name. This will force the name of the sub branch to be master.sub branch instead of simply sub branch.

For example, a tree has two branches FastTrack and SlowTrack, each containing an object of the same class (Track). To uniquely identify the sub branches we add the dot:

```
tree->Branch("FastTrack.","Track",&b1,8000,1);
tree->Branch("SlowTrack.","Track",&b2,8000,1);
```

If Track has three members, Px, Py, Pz, the two instructions above will generate sub branches called:
FastTrack.Px, FastTrack.Py , FastTrack.Pz,
SlowTrack.Px, SlowTrack.Py , SlowTrack.Pz,

Autosave

`Autosave` gives the option to save all branch buffers every `n` bytes. We recommend using `Autosave` for large acquisitions. If the acquisition fails to complete, you can recover the file and all the contents since the last `Autosave`. To set the number of bytes between `Autosave` you can use the `TTree::SetAutosave()` method. You can also call `TTree::Autosave` in the acquisition loop every `n` entries.

References

This finishes the discussion of `TTrees`. You should now be able to create branches with an object, branches with a list of variables, and branches with an array. You should also have a good understanding when to use each type of branch, and when to split an object.

In this section, we covered the objects in the table below. To find more information about them, follow the links to the ROOT system page.

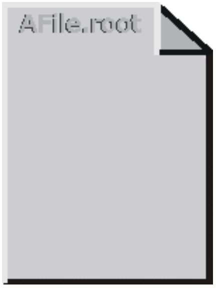
TTree	http://root.cern.ch/root/html/TTree.html
TBranch	http://root.cern.ch/root/html/TBranch.html
TLeaf	http://root.cern.ch/root/html/TLeaf.html
TClonesArray	http://root.cern.ch/root/html/TClonesArray.html
TObjArray	http://root.cern.ch/root/html/TObjArray.html

A good example of building a tree with event objects is given in `$ROOTSYS/test/MainEvent.cxx.`

Five-Steps to Build A Tree

Now that we know what a `TFile`, a `TTree`, and a `TBranch` are, we can put them to use and build a tree to save our data to a file. We use a five-step recipe to do this:

1. Create the `TFile` for writing
2. Create the `TTree`
3. Add `TBranches` to the `TTree`
4. Fill the `TTree`
5. Write the `TTree` to the `TFile`



Step 1: Create the TFile for writing

We create a `TFile`, by using the `TFile` constructor with the "`RECREATE`" option. The second line loads the shared library `libEvent.so`. We need the library, to provide the definition of the `Event` class that we will be saved in our tree (see building `libEvent.so`).

```
root [] TFile *f = new TFile("AFile.root", "RECREATE",
"Example")
root [] .L $ROOTSYS/test/libEvent.so
```

This creates a ROOT file with the name `AFile.root`. The "`RECREATE`" option requests the file to be overwritten if it already exists. The other options are:

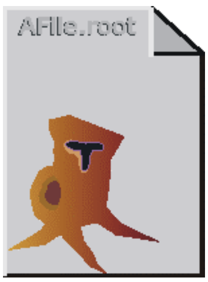
"`NEW`" - if the file exists this will generate an error.

"`CREATE`" - same as new

"`UPDATE`" - update or append an existing file

"`READ`" - open the file for read only

Step 2: Create a TTree



We now create an empty tree by using the `TTree` constructor. The listing of the directory (file) shows the new object, a `TTree` called "T". The `TTree` constructor takes up to three arguments. The first is the name of the tree, the second the title. The third parameter is called `maxvirtualsize`. It specifies the `fMaxVirtualSize` attribute of the Tree. Each branch has its list of buffers, and branch buffers may automatically be written to disk or kept in memory until the Tree attribute `fMaxVirtualSize` is reached.

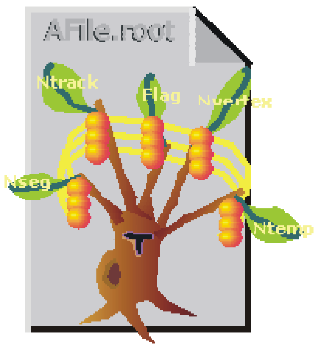
```
root [] TTree *tree = new TTree("T", "A Root tree");
root [] f->ls()
TFile**          AFile.root       Example
 TFile*          AFile.root       Example
  OBJ: TTree     T        A Root tree : 0
```

Step 3: Adding Branches

In our case, we want to write a series of events to the tree. We have an `event` object and we would like to add a branch holding the `event` object. We split the branch, so that we can see each leaf in the browser.

The `event` object is defined in `$ROOTSYS/test/Event.h`. You may want to open `$ROOTSYS/test/Event.h` in your editor now and note the data members and methods. If you are not on-line, there is a copy of `Event.h` in Appendix B: Event.h.

```
root[] Event *event = new  Event();
root[] tree->Branch ("EventBranch","Event",&event,64000,1);
```



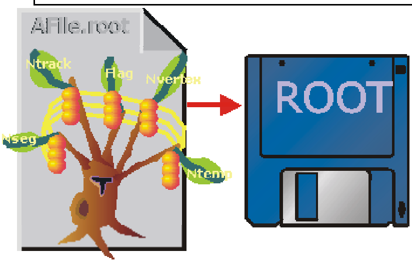
Step 4: Filling the TTree

To fill the tree we need to assign values to the event object and call the Fill method. We set the data members of the event object in a for-loop, and fill the tree each time.

The `TTree::Fill` method uses the tree structure we designed by adding branches of the correct type. In our example, it will create a tree with one branch per data member, and write the value of the data member to the branch for each `Fill`.

In this cartoon, the 'fruit' are the values of one event, and the lines show the collection of 'fruit' that are added to the tree for each call to `Fill`.

```
for (Int_t ev = 0; ev < 200; ev++) {
   Float_t  sigmat, sigmas;
   gRandom->Rannor(sigmat,sigmas);
   Int_t ntrack = Int_t (600 +600*sigmat/120.);
   Float_t random = gRandom->Rndm(1);
   event -> SetHeader(ev, 200, 960312, random);
   event -> SetNseg(Int_t (10*600+20*sigmas));
   event -> SetNvertex(1);
   event -> SetFlag(UInt_t (random+0.5));
   event -> SetTemperature(random+20.);
   for (Int_t t = 0; t < ntrack; t++)
      event->AddTrack(random);
   tree->Fill();   //fill the tree
   event->GetTracks()->Clear();
}
```



Step 5: Write the TFile to Disk

We have created a tree, and we see it in the file as an object in memory when doing an `ls()`.

```
root [] hfile->ls()
TFile**         AFile.root      An Example ROOT file
 TFile*         AFile.root      An Example ROOT file
  OBJ: TTree    T        A ROOT tree : 0
```

What would happen if we were to close the file now?

```
root [] hfile->Close()
```

The file would be saved, but it would be empty, because the objects in memory (`TTree T`, and `TH1F hstat`) were not written to the file. To save the tree and histogram to the file we need to call `TFile::Write`.

```
root [] hfile->Write()
root [] hfile->Close()
```

Using Trees in Analysis

In a collaboration many participants use existing trees and run their analysis on the data. This section is for these people. We will show you three methods in `TTree` that are good tools for analysis on an existing tree. These are the `TTree::Draw`, the `TTree::MakeClass`, and the `TTree::MakeSelector` methods.

The `TTree::Draw` method is a powerful yet simple way to look and draw the trees contents. It enables you to plot a variable (a leaf) with just one line of code. However, the Draw method falls short once you want to look at each entry and design more sophisticated acceptance criteria for your analysis. For these cases, you can use `TTree::MakeClass`. It creates a class that loops over the trees entries one by one. You can then expand it to do the logic of your analysis.

The `TTree::MakeSelector` method is useful to process a limited set of entries. This is especially important in a parallel processing configuration where the analysis is distributed over several processors and you can specify which entries to send to each processors.

Let us look at the `Draw` method first, with its powers and limitations. Then we will look at `MakeClass`.

Simple Analysis using TTree::Draw

We will be using the trees and files we created in section three "Five Steps to Build a Tree". If you had a chance to complete these, you can now use `AFile.root`.

First, open the file and lists its contents.

```
root [] TFile *p = new TFile("AFile.root", "READ")
root [] p->ls()
TFile**         AFile.root      An Example ROOT file
 TFile*         AFile.root      An Example ROOT file
  KEY: TTree    T;1     A ROOT tree
  KEY: TH1F     hstat;1 Event Histogram
```

We see the tree "T" in the file. This tree we will use to learn what the Draw method can do for us, so let’s get it:

```
root [] TTree *MyTree = T
```

CINT allows us to simply get the object by using it. Here we define a pointer to a `TTree` object and assign it the value of T, the tree in the file. CINT looks for T and returns it.

To show the different Draw options, we create a canvas with four sub-pads. We will use one sub-pad for each Draw command.

```
root [] TCanvas *myCanvas = new TCanvas("c","C",
0,0,600,400)
root [] myCanvas->Divide(2,2)
```

We activate the first pad with the `cd` statement:

```
root [] myCanvas->cd(1)
```

We then draw the variable `fNtrack`:

```
root [] MyTree->Draw("fNtrack");
```

As you can see this signature of Draw has only one parameter. It is a string containing the leaf name.

When a histogram is automatically created as a result of a `TTree::Draw`, the style of the histogram is inherited from the tree attributes and the current style (`gStyle`) is ignored. The tree attributes are the ones set in the current `TStyle` at the time the tree was created. You can call the method `TTree::useCurrentStyle` to change the histogram to use the current style at the time the histogram is created (**`gStyle`**, see the Chapter Graphics and Graphic User Interfaces).

In this next segment we activate the second pad and use two variables :

```
root [] myCanvas->cd(2)
root [] MyTree->Draw("sqrt(fNtrack):fNtrack");
```

This signature still only has one parameter, but it now has two dimensions separated by a colon (“`x:y`”). The item to be plotted can be an expression not just a simple variable. In general, this parameter is a string that contains up to three expressions, one for each dimension, separated by a colon (“`e1:e2:e3`”).

Using Selection with TTree:Draw

Change the active pad to 3, and add a selection to the list of parameters of the draw command.

```
root[] myCanvas->cd(3)
root[] MyTree->Draw("sqrt(fNtrack):fNtrack","fTemperature > 20.8");
```

This will draw the `fNtrack` for the entries with a temperature above 20.8 degrees. In the selection parameter, you can use any C++ operator, plus some functions defined in `TFormula`.

The value of the selection is used as a weight when filling the histogram. If the expression includes only Boolean operations as in the example above, the result is 0 or 1. If the result is 0, the histogram is not filled. In general, the expression is:

```
Selection = "weight *(boolean expression)"
```

If the Boolean expression evaluates to true, the histogram is filled with a weight. If the weight is not explicitly specified it is assumed to be 1.

For example, this selection will add 1 to the histogram if x is less than y and the square root of z is less than 3.2.

```
    "x<y && sqrt(z)>3.2"
```

On the other hand, this selection will add `x+y` to the histogram if the square root of z is larger than 3.2..

```
"(x+y)*(sqrt(z)>3.2)"
```

The Draw method has its own parser, and it only looks in the current tree for variables. This means that any variable used in the selection must be defined in the tree. You cannot use an arbitrary global variable in the `TTree::Draw` method.

Using TCut Objects in TTree::Draw

The `TTree::Draw` method also accepts `TCut` objects. A `TCut` is a specialized string object used for `TTree` selections. A `TCut` object has a name and a title. It does not have any data members in addition to what it inherits from `TNamed`. It only adds a set of operators to do logical string concatenation. For example, assume:

```
cut1 = "x<1"  and cut2 = "y>2"
```

then

```
cut1 && cut2 will be the string "(x<1)&&(y>2)"
```

Operators =, +=, +, *, !, &&, || are overloaded, here are some examples:

```
root[]TCut c1 = "x<1"
root[]TCut c2 = "y<0"
root[]TCut c3 = c1&&c2
root[]MyTree.Draw("x", c1)
root[]MyTree.Draw("x", c1||"x>0")
root[]MyTree.Draw("x", c1&&c2)
root[]MyTree.Draw("x", "(x+y)"*(c1&&c2)
```

Using Draw Options in TTree::Draw

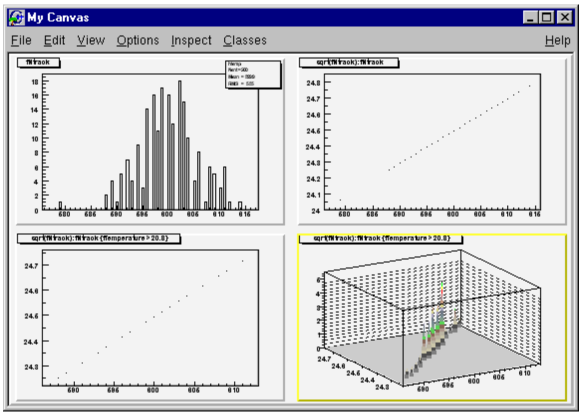
The next parameter is the draw option for the histogram:

```
root [] myCanvas->cd(4)
root [] MyTree->Draw("sqrt(fNtrack):fNtrack","fTemperature
> 20.8", "surf2");
```

The draw options are the same as for `TH1::Draw`, and they are listed in the section: Draw Options in the chapter on histograms. There is one additional draw option in the `TTree::Draw`; it is the "`prof`" option to generate a profile histogram from an expression with two variables rather than a regular 2D histogram.

You can combine them in a list separated by commas. If you specify the option "`goff`" no graphics will be generated.

After typing the lines above, you should now have a canvas that looks like this.



There is a case using the draw option "same" that is worth mentioning here. When superimposing two 2-D histograms inside a script with TTree::Draw and using the "same" option, you will need to update the pad between the calls to Draw.

In this example, h2->Draw is only adding the object h2 to the pad's list of primitives. It does not paint the object on the screen. However, TTree::Draw when called with option "same" gets the current pad coordinates to build an intermediate histogram with the right limits. Since nothing has been painted in the pad yet, the pad limits have not been computed. Calling pad->Update forces the painting of the pad and allows TTree::Draw to compute the right limits for the intermediate histogram.

```
// superimpose two 2D scatter plots
{
  // Create a 2D histogram and fill it with random numbers
  TH2 *h2 = new TH2D ("h2" ,"2D histo" ,40,0,4,30, 0,3);
  h2->FillRandom("gaus",10000);
  h2->Draw();

  // Open the example file and get the tree
  TFile f("AFile.root");
  TTree *myTree = (TTree*)f.Get("T");

  // the update is needed for the next draw command to
  // work properly
  gPad->Update();
  myTree->Draw("fTracks.fPy:fTracks.fPz", "","same",100,0);
}
```

Setting the Range in TTree::Draw

There are two more optional parameters to the Draw method: one is the number of entries and the second one is the entry to start with. We will show an example later. You can see the draw method is convenient.

Using Accessor methods in TTree::Draw

We have been using a tree where the object was split when the tree was built, and consequentially there is one branch for each variable. If the object was not split, and the entire event object is sitting on a branch, we can still use the draw method to plot a variable. However, the object has to provide an accessor method for the data member. In addition, the definition of the event object needs to be loaded into root. The syntax to draw with an accessor method is:

```
NonSplitTree->Draw("event->GetNtrack()")
```

We will show you later how to load the class and use the accessor method.

TTree::Draw with TClonesArray Branches

We previously added a branch with a `TClonesArray` branch. In such a branch we have created another dimension in the tree. The tree has now an array of objects for each entry. The curious mind will wonder if the association of the array with its entry will be preserved.

Let's take a hypothetical example (it is hypothetical because you will not be able to follow along). We have tree with 3 events and for each event we have a `TClonesArray` of tracks. Event #1 has 100 tracks, event #2 has 150 tracks, and event #3 has 200 tracks.

Each track has several data members as shown in the definition below:

```
class Track : public TObject {
private:
   Float_t      fPx;           //X component of the momentum
   Float_t      fPy;           //Y component of the momentum
   Float_t      fPz;           //Z component of the momentum
   Float_t      fRandom;       //A random track quantity
   Float_t      fMass2;        //The mass square of this particle
   Float_t      fBx;           //X intercept at the vertex
   Float_t      fBy;           //Y intercept at the vertex
   Float_t      fMeanCharge;   //Mean charge deposition of all hits
   Float_t      fXfirst;       //X coordinate of the first point
   Float_t      fXlast;        //X coordinate of the last point
   Float_t      fYfirst;       //Y coordinate of the first point
   Float_t      fYlast;        //Y coordinate of the last point
   Float_t      fZfirst;       //Z coordinate of the first point
   Float_t      fZlast;        //Z coordinate of the last point
   Float_t      fCharge;       //Charge of this track
   Int_t        fNpoint;       //Number of points for this track
   Short_t      fValid;        //Validity criterion
…
```

If we call the Draw method for the data member `fPx`, as follows:

```
Tree->Draw("fPx")
```

We will see a plot with all `fPx` values, which is: 100 + 150 + 200 = 450 tracks. We can limit the selection to just the tracks of the second event by using the conditional parameter of the `Draw` method.

```
Tree->Draw("fPx","","",1,2)
```

The plot drawn by this command will contain the `fPx` values from the 150 tracks in Event #2. Note that the middle two parameters are empty strings.

We can conclude that the association of the array and its entry is preserved in a `TClonesArray` branch.

Draw Branches with Arrays as Leaves

If you have a tree that has an array as a leaf, you can plot a specific index for all entries in the tree. Such a leaf looks like this when you issue the `TTree::Print` method:

```
*******************************************************
*Tree    :MyTree    : MyTree
…
*******************************************************
*Branch  :CH        : nch/I:chE[nch]/F:cheta[nch]/F:chphi[nch]/F
```

This tree, called `MyTree` has 1000 entries, and the first branch, the only one shown here is called `CH`. It contains an integer `nch`, and three floating point number arrays, `chE`, `cheta`, and `chphi`. Each array has `nch` elements. Here are some examples of the different Draw calls:

```
// draws all entries of chE (1000 * nch)
root[] MyTree->Draw("chE");
root[] MyTree->Draw("CH.chE");

// draws all entries of the third element in che (1000)
root[] MyTree->Draw("chE[3]");

// draws nch for all entries (1000)
root[] MyTree->Draw("CH");
```

Creating an Event List

The `TTree::Draw` method can also be used to build a list of the entries. When the first argument is preceded by `">>"` ROOT knows that this command is not intended to draw anything, but to save the entries in a list with the name given by the first argument. The resulting list is a `TEventList`, and is added to the objects in the current directory.

For example, to create a `TEventList` of all entries with more than 600 tracks:

```
root [] TFile *f = new TFile("AFile.root")
root [] T->Draw(">> myList", " fNtrack > 600")
```

This list contains the entry number of all entries with more than 600 tracks.

To see the entry numbers use the `Print("all")` command.

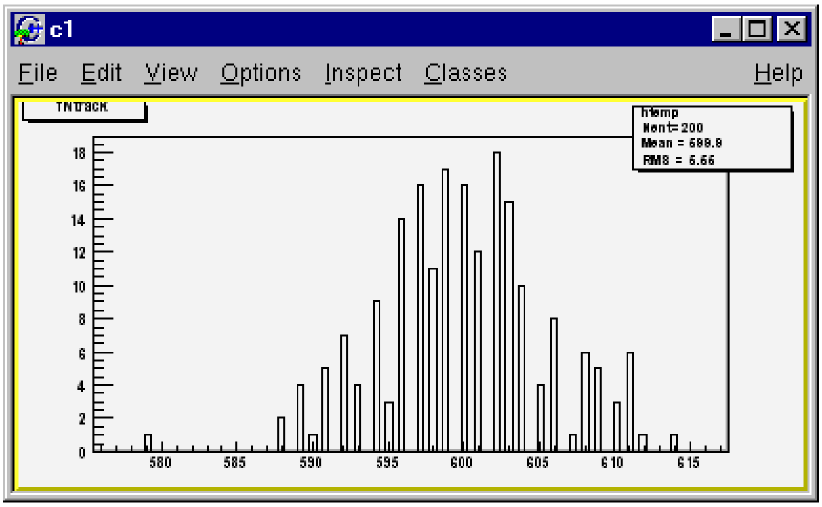
```
root [] myList->Print("all")
```

When using the `">>"` whatever was in the `TEventList` is overwritten. The `TEventList` can be grown by using the `">>+"` syntax.

For example to add the entries, with exactly 600 tracks:

```
root [] T->Draw(">>+ myList", " fNtrack == 600")
```

If the Draw command generates duplicate entries, they are not added to the list.




```
root [] T->Draw(">>+ myList", " fNtrack > 610")
```

This command does not add any new entries to the list because all entries with more than 610 tracks have already been found by the previous command for entries with more than 600 tracks.

Using an Event List

The `TEventList` can be used to limit the `TTree` to the events in the list. The `SetEventList` method tells the tree to use the event list and hence limits all subsequent `TTree` methods to the entries in the list. In this example, we create a list with all entries with more than 600 tracks and then set it so the Tree will use this list. To reset the `TTree` to use all events use `SetEventList(0)`.

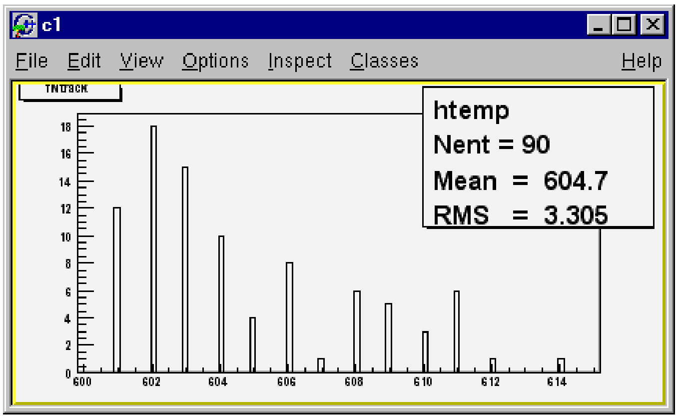
1) Let's look at an example. First, open the file and draw the `fNtrack`.

```
root [] TFile *f = new TFile("AFile.root")
```

root [] `T->Draw("fNtrack ")` 2) Now, put the entries with over 600 tracks into a `TEventList` called `myList`. We get the list from the current directory and assign it to a variable list.

```
root [] T->Draw(">>myList", " fNtrack >600")
root [] TEventList *list = (TEventList*)gDirectory->Get("myList")
```

3) Instruct the tree T to use the new list and draw it again. Note that this is exactly the same Draw command. The list limits the entries.




```
root [] T->SetEventList(list)
root [] T->Draw("fNtrack ")
```

You should now see a canvas that looks like this one.

Creating a Histogram

The `TTree::Draw` method can also be used to fill a specific histogram. The syntax is:

```
root [] TFile *f = new TFile("AFile.root")
root [] T->Draw("fNtrack >> myHisto")
root [] myHisto->Print()
TH1.Print Name= myHisto, Total sum= 200
```

As we can see, this created a `TH1`, called `myHisto`. If you want to append more entries to the histogram, you can use this syntax:

```
root [] T->Draw("fNtrack >>+ myHisto")
```

If you do not construct a histogram ahead of time, ROOT will construct one at the time of the Draw command (as is the case above). If you would like to draw the variable into a specific histogram where you, for example, set the range and bin number, you can define the histogram ahead of time and use it in the Draw command. The histogram has to be in the same directory as the tree.

```
root[] TH1F *h1 = new TH1F("h1","h1",50, 0., 150.);
root[] T -> Draw("fNtrack>> h1");
```

When you project a `TTree` into a histogram, the histogram inherits the `TTree` attributes and not the current style attributes. This allows you to project two Trees with different attributes into the same picture. You can call the method `TTree::useCurrentStyle` to change the histogram to use the current style (**`gStyle`**, see the Chapter Graphics and Graphic User Interfaces).

Projecting a Histogram

If you would like to fill a histogram, but not draw it you can use the `TTree::Project()` method.

```
root [] T->Project("quietHisto","fNtrack")
```

Making a Profile Histogram

In case of a two dimensional expression, you can generate a `TProfile` histogram instead of a two dimensional histogram by specifying the '`prof'` or '`profs'` option. The `prof` option is automatically selected when the output is redirected into a `TProfile`. For example `y:x>>pf` where `pf` is an existing `TProfile` histogram.

Tree Information

Once we have drawn a tree, we can get information about the tree. These are the methods used to get information from a drawn tree:

- `GetSelectedRows`: Returns the number of entries accepted by the selection expression. In case where no selection was specified, it returns the number of entries processed.
- `GetV1`: Returns a pointer to the float array of the first variable.
- `GetV2`: Returns a pointer to the float array of second variable
- `GetV3`: Returns a pointer to the float array of third variable.
- `GetW`: Returns a pointer to the float array of Weights where the weight equals the result of the selection expression.

To read the drawn values of `fNtrack` into an array, and loop through the entries follow the lines below. First, open the file and draw the `fNtrack` variable:

```
root [] TFile *f = new TFile("AFile.root")
root [] T->Draw("fNtrack")
```

Then declare a pointer to a float and use the `GetV1` method to retrieve the first dimension of the tree. In this example we only drew one dimension (`fNtrack`) if we had drawn two, we could use `GetV2` to get the second one.

```
root [] Float_t *a
root [] a = T->GetV1()
```

Loop through the first 10 entries and print the values of `fNtrack`:

```
root [] for (int i = 0; i < 10; i++) cout<<a[i]<< " "
root [] cout << endl  // need an endl to see the values
594 597 606 595 604 610 604 602 603 596
```

By default, `TTree::Draw` creates these arrays with `fEstimate` words where `fEstimate` can be set via `TTree::SetEstimate`. If you have more entries than `fEstimate` only the first `fEstimate` selected entries will be stored in the arrays. The arrays are used as buffers. When `fEstimate` entries have been processed, ROOT scans the buffers to compute the minimum and maximum of each coordinate and creates the corresponding histograms.

You can use these lines to read all entries into these arrays:

```
root [] Int_t nestimate = (Int_t)T->GetEntries();
root [] T->SetEstimate(nestimate);
```

Obviously, this will not work if the number of entries is very large.
This technique is useful in several cases, for example if you want to draw a graph connecting all the x,y (or z) points. Note that you may have a tree (or chain) with 1 billion entries, but only a few may survive the cuts and will fit without problems in these arrays.

More Complex Analysis using TTree::MakeClass

The Draw method is convenient and easy to use, however it falls short if you need to do some programming with the variable.

For example, for plotting the masses of all oppositely changed pairs of tracks, you would need to write a program that loops over all events, finds all pairs of tracks, and calculates the required quantities. We have shown how to retrieve the data arrays from the branches of the tree in the previous section, and you could just write that program from scratch. Since this is a very common task, ROOT provides a utility that generates a skeleton class designed to loop over the entries of the tree. This is `the TTree::MakeClass` method

We will now go through the steps of using `MakeClass` with a simplified example. The methods used here obviously work for much more complex event loop calculations.

These are our assumptions:

We would like to do selective plotting and loop through each entry of the tree and tracks. We chose a simple example: we want to plot `fPx` of the first 100 tracks of each entry.

We have a ROOT tree with one branch, containing the entire (un-split) "Event" object. To build this file and tree follow the instructions on how to build the examples in `$ROOTSYS/test`.

Execute Event and instruct it not to split the object with this command (from the Unix command line).

```
> Event 400 1 0 1
```

This command creates an `Event.root` file with 400 events, compressed, not split, and filled. See `$ROOTSYS/test/MainEvent.Cxx` for more info.

The person who designed the tree makes a shared library available to you, which defines the classes needed. In this case, the classes are `Event`, `EventHeader`, and `Track` and they are defined in the shared library `libEvent.so`. The designer also gives you the `Event.h` file to see the definition of the classes. You can locate `Event.h` in `$ROOTSYS/test`, and if you have not yet built `libEvent.so`, please see the instructions of how to build it. If you have already built it, you can now use it again.

Creating a Class with MakeClass

First, we load the shared library and open `Event.root`.

```
root [] .L libEvent.so
root [] TFile *f = new TFile ("Event.root");
root [] f->ls();
TFile**         Event.root      TTree benchmark ROOT file
 TFile*         Event.root      TTree benchmark ROOT file
  KEY: TH1F     htime;1 Real-Time to write versus time
  KEY: TTree    T;1     An example of a ROOT tree
  KEY: TH1F     hstat;1 Event Histogram
```

We can see there is a tree "`T`", and just to verify that we are working with the correct one, we print the tree, which will show us the header and branches. From this we can see that we have one branch called event.

```
root [] T->Print();
*********************************************************
*Tree    :T         : An example of a ROOT tree
*Entries :      400 : Total  Size =  19321594 bytes  …
*        :          : Tree compression factor =   1.51
*********************************************************
*Branch  :event     : event
*Entries :      400 : Total  Size =  19319604 bytes  …
*Baskets :       80 : Basket Size =    256000 bytes  …
*........................................................
```

Now we can use the `TTree::MakeClass` method on our tree "`T`". `MakeClass` takes one parameter, a string containing the name of the class to be made.

In the command below, the name of our class will be "`MyClass`".

```
root [] T->MakeClass("MyClass")
Files: MyClass.h and MyClass.C generated from Tree: T
(Int_t)0
```

CINT informs us that it has created two files. `MyClass.h`, which contains the class definition and `MyClass.C`, which contains the `MyClass::Loop` method. `MyClass` has more methods than just `Loop`. The other methods are: a constructor, a destructor, `GetEntry`, `LoadTree`, `Notify`, and `Show`. The implementation of these methods is in the .h file. This division of methods was done intentionally. The .C file is kept as short as possible, and contains only code that is intended for you to customize. The .h file contains all the other methods.

To start with, it helps to understand both files, so lets start with `MyClass.h` and the class definition:

MyClass.h

```
class MyClass {
   public :
      //pointer to the analyzed TTree or TChain
      TTree          *fTree;
      //pointer to the current TTree
      TTree          *fCurrent;
      //Declaration of leaves types
      Event          *event;
      //List of branches
      TBranch        *b_event;
      //Methods
      MyClass(TTree *tree=0);
      ~MyClass();
      Int_t GetEntry(Int_t entry);
      Int_t LoadTree(Int_t entry);
      void  Init(TTree *tree);
      void  Loop();
      void  Notify();
      void  Show(Int_t entry = -1);
};
```

We can see four data members in the generated class. The first data member is `fTree`. Once this class is instantiated, `fTree` will point to the original tree this class was made from. In our case, this is “`T`” in “`Event.root`”. If the class is instantiated with a tree as a parameter to the constructor, `fTree` will point to the tree named in the parameter.

Next is `fCurrent`, which is also a pointer to the current tree. Its role is only relevant once we have multiple trees chained together in a `TChain`.

The class definition shows us that this tree has one branch and one leaf. In `MyClass`, the branch name is `b_event` and the leaf is called event and is of the Event class.

If we had split the event branch when creating the tree, there would be one data member for each leaf, and one `TBranch` data member for each branch.

```
class SplitClass {
…
//Declaration of leaves types
   Int_t            fNtrack;
   Int_t            fNseg;
   Int_t            fNvertex;
   UInt_t           fFlag;
…
//List of branches
   TBranch         *b_event;
   TBranch         *b_fNtrack;
   TBranch         *b_fNseg;
   TBranch         *b_fNvertex;
   TBranch         *b_fFlag;
…
```

You can find the complete listing of “`SplitClass`” in Appendix C: Split Class.

Let’s go back to the definition of `MyClass`, and go through the methods.

- `MyClass(TTree *tree=0)`: This constructor has an optional tree for a parameter. If you pass a tree, `MyClass` will use it rather than the tree from which it was created.
- `void Init(TTree *tree)`: Init is called by the constructor to initialize the tree for reading. It associates each branch with the corresponding leaf data member.
- `~MyClass()`:This is the destructor, nothing special.
- `Int_t GetEntry(Int_t entry)`: This loads the class with the entry specified. Once you have executed `GetEntry`, the leaf data members in `MyClass` are set to the values of the entry. For example, `GetEntry(12)` loads the 13th event into the event data member of `MyClass` (note that the first entry is 0).
  `GetEntry` returns the number of bytes read from the file. In case the same entry is read twice, ROOT does not have to do any I/O. In this case `GetEntry` returns 1. It does not return 0, because many people assume a return of 0 means an error has occurred while reading.
- `Int_t LoadTree(Int_t entry) and void Notify()`:
  These two methods are related to chains. `LoadTree` will load the tree containing the specified entry from a chain of trees. `Notify` is called by `LoadTree` to adjust the branch addresses.
- `void Loop()`: This is the skeleton method that loops through each entry of the tree. This is interesting to us, because we will need to customize it for our analysis.

This covers `MyClass.h;` now open `MyClass.C` with your editor. Here we see the implementation of `MyClass::Loop()`.

MyClass.C

`MyClass::Loop` consists of a for-loop calling `GetEntry` for each entry. In the skeleton, the numbers of bytes are added up, but it does nothing else. If we were to execute it now, there would be no output.

```
void MyClass::Loop()
{
   if (fTree == 0) return;
   Int_t nentries = Int_t(fTree->GetEntries());
   Int_t nbytes = 0, nb = 0;
   for (Int_t i=0; i<nentries;i++) {
      if (LoadTree(i) < 0) break;
      nb = fTree->GetEntry(i);   nbytes += nb;
   }
}
```

At the beginning of the file are instructions about reading only selected branches. They are not reprinted here, but please read them from your own file. In our example, we only have one branch, so we can stick with `GetEntry` and read the entire entry.

Modifying MyClass::Loop

Lets continue with the goal of going through the first 100 tracks of each entry and plot `Px`. To do this we change the Loop method.

Since we will be dealing with tracks, we need two temporary variables. We will need a pointer to a track and an integer to hold the number of tracks. We also need to create two histograms, one to hold `fPx` of the first 100 tracks and one to hold all values of `fPx`.

```
  …
  if (fTree == 0) return;
  Track *track      = 0;
  Int_t n_Tracks = 0;
  TH1F *myHisto     = new TH1F("myHisto","fPx", 100, -5,5);
  TH1F *smallHisto = new TH1F("small","fPx", 100, -5,5);
…
```

In the for-loop, we need to add another for-loop to go over all the tracks.
In the outer for-loop, we get the entry and the number of tracks.
In the inner for-loop, we fill the large histogram (`myHisto`) with all tracks and the small histogram (`smallHisto`) with the track if it is in the first 100.

```
…
  for (Int_t i=0; i<nentries;i++) {
       if (LoadTree(i) < 0) break;
       GetEntry(i);
       n_Tracks = event->GetNtrack();
       for (Int_t j = 0; j < n_Tracks; j++){
         track = (Track*) event->GetTracks()->At(j);
         myHisto->Fill(track->GetPx());
        if (j < 100){
          smallHisto->Fill(track->GetPx());
         }
       }
  }
…
```

This statement could use some explanation.

```
track = (Track*) event->GetTracks()->At(j);
```

Remember that the tracks in the event are in a `TClonesArray`. The `Event::GetTracks` method returns the clones array of tracks for that event. The method `TClonesArray::At(n)` retrieves the n^{th} element in the array. However, the return of `At(n)` is a pointer to `TObject`. So, for us to be of any use we have to cast the result to pointer to a Track object.

Outside of the for-loop, we draw both histograms on the same canvas.

```
…
myHisto->Draw();
smallHisto->Draw("Same");
…
```

Save these changes to `MyClass.C` and start a fresh root session. We will now load `MyClass` and experiment with its methods.

Loading MyClass

The first step is to load the library and the class file. Then we can instantiate a `MyClass` object.

```
root [] .L libEvent.so
root [] .L MyClass.C
root [] MyClass m
```

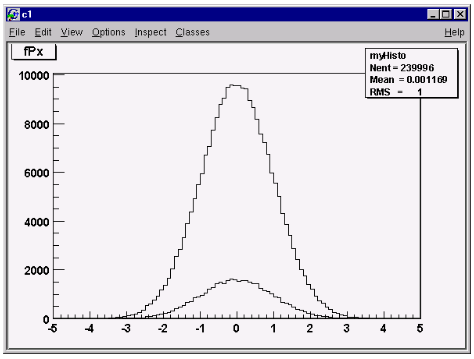
Now we can get a specific entry and populate the event leaf. In the code snipped below, we get entry 0, and print the number of tracks (594). Then we get entry 1 and print the number of tracks (597).

```
root [] m.GetEntry(0)
(int)57503
root [] m.event->GetNtrack()
(Int_t)594
root [] m.GetEntry(1)
(int)48045
root [] m.event->GetNtrack()
(Int_t)597
```

Now we can call the Loop method, which will build and display the two histograms.

```
root [] m.Loop()
```

You should now see a canvas that looks like this.



To conclude the discussion on `MakeClass` let's lists the steps that got us here.

- Call `TTree::MakeClass`, which automatically creates a class to loop over the tree.
- Modify the `MyClass::Loop()` method in `MyClass.C` to fit your task.
- Load and instantiate `MyClass`, and run `MyClass::Loop()`.

Analysis using Selectors

With a `TTree` we can make a selector and use it to process a limited set of entries. This is especially important in a parallel processing configuration where the analysis is distributed over several processors and we can specify which entries to send to each processors. The `TTree::Process` method is used to specify the selector and the entries.

Before we can use `TTree::Process` we need to make a selector. We can call the `TTree::MakeSelector` method. It creates two files similar to `TTree::MakeClass`. In the resulting files is a class that is a descendent of `TSelector` and implements the following methods:

- `TSelector::Begin`: This function is called every time a loop over the tree starts. This is a convenient place to create your histograms.
- `TSelector::Notify()`: This function is called at the first entry of a new tree in a chain.
- `TSelector::ProcessCut`: This function is called at the beginning of each entry to return a flag true if the entry must be analyzed.

- `TSelector::ProcessFill`: This function is called in the entry loop for all entries accepted by Select.
- `TSelector::Terminate`: This function is called at the end of a loop on a `TTree`. This is a convenient place to draw and fit your histograms.

The `TSelector`, unlike the resulting class from `MakeClass`, separates the processing into a `ProcessCut` and `ProcessFill`, so that we can limit reading the branches to the ones we need.

To create a selector call:

```
root[] T->MakeSelector("MySelector");
```

Where `T` is the `TTree` and `MySelector` is the name of created class and the name of the .h and .C files.

The resulting `TSelector` is the argument to `TTree::Process`. The argument can be the file name or a pointer to the selector object.

```
root[] T->Process("MySelector.C",1000,100);
```

This call will interpret the class defined in `MySelector.C` and process 1000 entries beginning with entry 100. The file name can be appended with a "+" or a "++" to use `ACLiC`.

```
root[] T->Process("MySelector.C++",1000,100);
```

When appending a "++", the class will be compiled and dynamically loaded.

```
root[] T->Process("MySelector.C+",1000,100);
```

When appending a "+", the class will also be compiled and dynamically loaded. When it is called again, it recompiles only if the macro (`MySelector.C`) has changed since it was compiled last. If not it loads the existing library.

`TTree::Process` is aware of PROOF, ROOT's parallel processing facility. If PROOF is setup, it divides the processing amongst the slave CPUs.

Please see the chapter **Example Analysis** for an example of using a selector on a large data set.

Chains

A `TChain` object is a list of ROOT files containing the same tree. As an example, assume we have three files called `file1.root, file2.root, file3.root`. Each file contains one tree called "`T`". We can create a chain with the following statements:

```
TChain chain("T");   // name of the tree is the argument
chain.Add("file1.root");
chain.Add("file2.root");
chain.Add("file3.root");
```

The name of the `TChain` will be the same as the name of the tree, in this case it will be `"T"`. Note that two objects can have the same name as long as they are not histograms in the same directory, because there, the histogram names are used to build a hash table.

The class `TChain` is derived from the class `TTree`. For example, to generate a histogram corresponding to the attribute "x" in tree "T" by processing sequentially the three files of this chain, we can use the `TChain::Draw` method.

```
chain.Draw("x");
```

The following statements illustrate how to set the address of the object to be read and how to loop on all events of all files of the chain.

```
{
   TChain chain("T");      // create the chain with tree "T"
   chain.Add("file1.root"); // add the files
   chain.Add("file2.root");
   chain.Add("file3.root");

   TH1F *hnseg = new TH1F("hnseg","Number of segments for
selected tracks",5000,0,5000);

 // create an object before setting the branch address
   Event *event = new Event();
 // Specify the address where to read the event object
   chain.SetBranchAddress("event", &event);

 // Start main loop on all events
 // In case you want to read only a few branches, use
 // TChain::SetBranchStatus to activate a branch.
   Int_t nevent = chain.GetEntries();
   for (Int_t i=0;i<nevent;i++) {
      // read complete accepted event in memory
      chain.GetEvent(i);
      // Fill histogram with number of segments
      hnseg->Fill(event->GetNseg());
   }

 // Draw the histogram
   hnseg->Draw();
}
```

References

In this section, we covered the objects in the table below. To find more information about them, follow the links to the ROOT system page.

TTree	http://root.cern.ch/root/html/TTree.html
TBranch	http://root.cern.ch/root/html/TBranch.html
TClonesArray	http://root.cern.ch/root/html/TClonesArray.html
TEventList	http://root.cern.ch/root/html/TEventList.html
TFormula	http://root.cern.ch/root/html/TFormula.html
TCanvas	http://root.cern.ch/root/html/TCanvas.html
TChain	http://root.cern.ch/root/html/TChain.html

11 Adding a Class

Motivation

If you want to integrate and use your classes with ROOT, to enjoy features like, extensive RTTI (Run Time Type Information) and ROOT object I/O and inspection, you have to add the following line to your class header files:

```
ClassDef (ClassName,ClassVersionID)  //The class title
```

For example in `TLine.h` we have:

```
ClassDef (TLine,1)  //A line segment
```

The **`ClassVersionID`** is used by the ROOT I/O system. It is written on the output stream and during reading you can check this version ID and take appropriate action depending on the value of the ID (see the section on Streamers in the Chapter Input/Output). Every time you change the data members of a class, you should increase its `ClassVersionID` by one. The `ClassVersionID should be >=1`. Set `ClassVersionID=0` in case you don't need object I/O.

Similarly, in your implementation file you must add the statement:

```
ClassImp(ClassName)
```

For example in `TLine.cxx`:

```
ClassImp(TLine)
```

Note that you **MUST** provide a default constructor for your classes, i.e. a constructor with zero parameters or with one or more parameters all with default values in case you want to use object I/O. If not you will get a compile time error.

The **`ClassDef`** and **`ClassImp`** macros are necessary to link your classes to the dictionary generated by CINT.

The `ClassDef` and `ClassImp` macros are defined in the file **`Rtypes.h`**. This file is referenced by all ROOT include files, so you will automatically get them if you use a ROOT include file.

The Default Constructor

ROOT object I/O requires every class to have a default constructor. This default constructor is called whenever an object is being read from a ROOT database. Be sure that you don't allocate any space for embedded pointer objects in the default constructor. This space will be lost (memory leak) while reading in the object. For example:

```
class T49Event : public TObject {
private:
   Int_t        fId;
   TCollection *fTracks;
   ...
   ...
public:
   // Error space for TList pointer will be lost
   T49Event() { fId = 0; fTrack = new TList; }
   // Correct default initialization of pointer
   T49Event() { fId = 0; fTrack = 0; }
   ...
   ...
};
```

The memory will be lost because during reading of the object the pointer will be set to the object it was pointing to at the time the object was written.

Create the **`fTrack`** list when you need it, e.g. when you start filling the list or in a **not-default** constructor.

```
...
if (!fTrack) fTrack = new TList;
...
```

rootcint: The CINT Dictionary Generator

In the following example we walk through the steps necessary to generate a dictionary and I/O and inspect member functions.

Let start with a `TEvent` class, which contains a collection of `TTracks`:

```
#ifndef __TEvent__
#define __TEvent__

#include "TObject.h"

class TCollection;
class TTrack;


class TEvent : public TObject {

private:
   Int_t        fId;          // event sequential id
   Float_t      fTotalMom;    // total momentum
   TCollection *fTracks;      // collection of tracks

public:
   TEvent() { fId = 0; fTracks = 0; }
   TEvent(Int_t id);
   ~TEvent();

   void    AddTrack(TTrack *t);
   Int_t   GetId() const { return fId; }
   Int_t   GetNoTracks() const;
   void    Print(Option_t *opt="");
   Float_t TotalMomentum();

   ClassDef (TEvent,1)  //Simple event class
};
```

And the TTrack header:

```
#ifndef __TTrack__
#define __TTrack__

#include "TObject.h"

class TEvent;


class TTrack : public TObject {

private:
   Int_t    fId;       //track sequential id
   TEvent  *fEvent;    //event to which track belongs
   Float_t  fPx;       //x part of track momentum
   Float_t  fPy;       //y part of track momentum
   Float_t  fPz;       //z part of track momentum

public:
   TTrack() { fId = 0; fEvent = 0; fPx = fPy = fPz = 0; }
   TTrack(Int_t id, Event *ev, Float_t px,Float_t py,Float_t pz);

   Float_t  Momentum() const;
   TEvent  *GetEvent() const { return fEvent; }
   void     Print(Option_t *opt="");

   ClassDef (TTrack,1)  //Simple track class
};

#endif
```

The things to notice in these header files are:

- The usage of the ClassDef macro
- The default constructors of the TEvent and TTrack classes
- Comments to describe the data members and the comment after the ClassDef macro to describe the class

These classes are intended for you to create an event object with a certain id, and then add tracks to it. The track objects have a pointer to their event. This shows that the I/O system correctly handles circular references.

Next, the implementation of these two classes. `Event.cxx`:

```
#include <iostream.h>

#include "TOrdCollection.h"
#include "TEvent.h"
#include "TTrack.h"


ClassImp(TEvent)

...
...
```

and `Track.cxx:`

```

#include <iostream.h>

#include "TMath.h"
#include "Track.h"
#include "Event.h"

ClassImp(TTrack)
...
```

Now using **`rootcint`** we can generate the dictionary file.

Make sure you use a unique filename, because `rootcint` appends it to the name of static function (`G__cpp_reset_tabableeventdict()` and `G__set_cpp_environmenteventdict ()`).

```
rootcint eventdict.cxx -c TEvent.h TTrack.h
```

Looking in the file `eventdict.C` we can see, besides the many member function calling stubs (used internally by the interpreter), the `Streamer()` and `ShowMembers()` methods for the two classes. `Streamer()` is used to stream an object to/from a `TBuffer` and `ShowMembers()` is used by the `Dump()` and `Inspect()` methods of `TObject`.

Here is the `TEvent::Streamer` method:

```
void TEvent::Streamer(TBuffer &R__b)
{
   // Stream an object of class TEvent.
   if (R__b.IsReading()) {
      Version_t R__v = R__b.ReadVersion();
      TObject::Streamer(R__b);
      R__b >> fId;
      R__b >> fTotalMom;
      R__b >> fTracks;
   } else {
      R__b.WriteVersion(TEvent::IsA());
      TObject::Streamer(R__b);
      R__b << fId;
      R__b << fTotalMom;
      R__b << fTracks;
   }
}
```

The `TBuffer` class overloads the `operator<<()` and `operator>>()` for all basic types and for pointers to objects. These operators write and read from the buffer and take care of any needed byte swapping to make the buffer machine independent. During writing the `TBuffer` keeps track of the objects that have been written and multiple references to the same object are replaced by an index. In addition, the object's class information is stored.

`TEvent` and `TTracks` need manual intervention. Cut and paste the generated `Streamer()` from the `eventdict.C` into the class' source file and modify as needed (e.g. add counter for array of basic types) and disable the generation of the `Streamer()` when using the `LinkDef.h` file for next execution of `rootcint`.

To disable the generation of the `Streamer`, change this line in the class source file:

```
ClassDef (TEvent,0)
```

Adding a Class with a Shared Library

Step 1:
Define your own class in `SClass.h` and implement it in `SClass.cxx`. You must provide a default constructor for your class.

```
#include <iostream.h>
#include "TObject.h"
class SClass : public TObject {
private:
   Float_t   fX;          //x position in centimeters
   Float_t   fY;          //y position in centimeters
   Int_t     fTempValue; //! temporary state value
public:
   SClass()             { fX = fY = -1; }
   void Print() const;
   void SetX(float x) { fX = x; }
   void SetY(float y) { fY = y; }

   ClassDef (SClass, 1)
};
```

Step 2:
Add a call to the `ClassDef` macro to at the end of the class definition (i.e. in the `SClass.h` file). `ClassDef(SClass,1)`.

Add a call to the `ClassImp` macro in the implementation file (`SClass .cxx`). `ClassImp(SClass)`

`SClass.cxx:`

```
#include "SClass.h"
ClassImp (SClass);
void SClass::Print() const {
   cout << "fX = " << fX << ", fY = " << fY << endl;
}
```

You can add a class without using the `ClassDef` and `ClassImp` macros, however you will be limited. Specifically the object I/O features of ROOT will not be available to you for these classes (see the chapter "CINT the C++ Interpreter").

The `ShowMembers`() and `Streamer`() method, as well as the `>> operator` overloads, are implemented only if you use `ClassDef` and `ClassImp`.

See http://root.cern.ch/root/html/Rtypes.h for the definition of `ClassDef` and `ClassImp`.

To exclude a data member from the Streamer, add a ! as the first character in the comments of the field:

```
   Int_t     fTempValue; //! temporary state value
```

Step 3:
The `LinkDef.h` file tells `rootcint` for which classes the method interface stubs should be generated

```
#ifdef __CINT__
#pragma link off all globals;
#pragma link off all classes;
#pragma link off all functions;
#pragma link C++ class SClass;
#endif
```

Three options can trail the class name:

- `-` : tells `rootcint` **not** to generate the `Streamer()` method for this class. This is necessary for those classes that need a customized `Streamer()` method.

```
#pragma link C++ class SClass-; // no streamer
```

- `!` : tells `rootcint` **not** to generate the `operator>>(TBuffer &b, MyClass *&obj)` method for this class. This is necessary to be able to write pointers to objects of classes not inheriting from `TObject`.

```
#pragma link C++ class SClass!;  // no >> operator
or
#pragma link C++ class SClass-!; // no Streamer no >>
operator
```

- + : in ROOT version 1 and 2 tells `rootcint` to generate a `Streamer()` with extra byte count information. This adds an integer to each object in the output buffer, but it allows for powerful error correction in case a `Streamer()` method is out of sync compared to the data on the file. The + option is mutual exclusive with both the - and ! options.

IMPORTANT NOTE: In ROOT Version 3, a "+" after the class name will tell `rootcint` to use the new I/O system. The byte count check is always added. See: How To Use the New I/O System.

```
#pragma link C++ class SClass+; // add byte count
```

For information on `Streamers` see the section on Streamers in the Input/Output chapter.

To get help on rootcint type: `rootcint -?` on the UNIX command line.

Step 4: Compile the class using the Makefile

In the Makefile call `rootcint` to make the dictionary for the class. Call it `SClassDict.cxx`. The rootcint utility generates the `Streamer`(), `TBuffer &operator>>()` and `ShowMembers`() methods for ROOT classes.

For more information on `rootcint` follow this link: http://root.cern.ch/root/RootCintMan.html

Also, see the `$ROOTSYS/test` directory `Makefile`, `Event.cxx`, and `Event.h` for an example.

```
gmake -f Makefile
```

Load the shared library:

```
 root [] .L SClass.so
 root [] SClass *sc = new SClass()
 root [] TFile *f = new TFile("Afile.root", "UPDATE");
 root [] sc->Write();
```

Adding a Class with ACLiC

Step 1. Define your class

```
#include "TObject.h"
// define the ABC class and make it inherit
// from TObject so that we can write ABC to a ROOT file
class ABC : public TObject {
  public:
  Float_t a,b,c,p;
  ABC():a(0),b(0),c(0),p(0){};

  // Define the class for the cint dictionary
  ClassDef (ABC,1)
};

// Call the ClassImp macro to give the ABC class RTTI
// and full I/O capabilities.

  #if !defined(__CINT__)
    ClassImp(ABC);
  #endif
```

Step 2: Load the ABC class in the script.

```
// Check if ABC is already loaded
if (!TClassTable::GetDict("ABC")) {
      gROOT->Macro("ABCClass.C++");
}
// Use the Class
ABC *v = new ABC;
v->p = (sqrt((v->a * v->a)+ (v->b * v->b)+(v->c * v->c)));
```

12 Collection Classes

Collections are a key feature of the ROOT system. Many, if not most, of the applications you write will use collections. If you have used parameterized C++ collections or polymorphic collections before, some of this material will be review. However, much of this chapter covers aspects of collections specific to the ROOT system. When you have read this chapter, you will know

- How to create instances of collections
- The difference between lists, arrays, hash tables, maps, etc.
- How to add and remove elements of a collection
- How to search a collection for a specific element
- How to access and modify collection elements
- How to iterate over a collection to access collection elements
- How to manage memory for collections and collection elements
- How collection elements are tested for equality (`IsEqual()`)
- How collection elements are compared (`Compare()`) in case of sorted collections
- How collection elements are hashed (`Hash()`) in hash tables

Understanding Collections

A collection is a group of related objects. You will find it easier to manage a large number of items as a collection. For example, a diagram editor might manage a collection of points and lines. A set of widgets for a graphical user interface can be placed in a collection. A geometrical model can be described by colections of shapes, materials and rotation matrices. Collections can themselves be placed in collections. Collections act as flexible alternatives to traditional data structures of computers science such as arrays, lists and trees.

General Characteristics

The ROOT collections are polymorphic containers that hold pointers to `TObjects`, so:

- They can only hold objects that inherit from `TObject`
- They return pointers to `TObjects`, that have to be cast back to the correct subclass

Collections are dynamic, they can grow in size as required.

Collections themselves are descendants of `TObject` so can themselves be held in collections. It is possible to nest one type of collection inside another to any level to produce structures of arbitrary complexity.

Collections don't own the objects they hold for the very good reason that the same object could be a member of more than one collection. Object ownership is important when it comes to deleting objects; if nobody owns the object it could end up as wasted memory (i.e. a memory leak) when no longer needed. If a collection is deleted, its objects are not. The user can force a collection to delete its objects, but that is the user's choice.

Determining the Class of Contained Objects

Most containers may hold heterogeneous collections of objects and then it is left to the user to correctly cast the `TObject` pointer to the right class. *Casting to the wrong class will give wrong results and may well crash the program!* So the user has to be very careful. Often a container only contains one class of objects, but if it really contains a mixture, it is possible to ask each object about its class using the `InheritsFrom()` method.

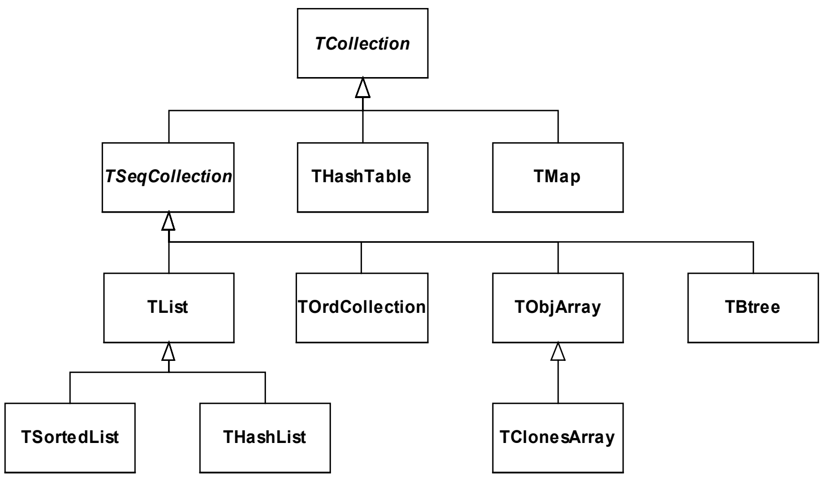
For example if `myObject` is a `TObject` pointer:

```
if (myObject->InheritsFrom("TParticle") {
   printf("myObject is a TParticle\n");
}
```

As the name suggests, this test works even if the object is a subclass of `TParticle`. The member function `IsA()` can be used instead of `InheritsFrom()` to make the test exact. The `InheritsFrom()` and `IsA()` methods use the extensive Run Time Type Information (RTTI) available via the ROOT meta classes.

Types of Collections

The ROOT system implements the following basic types of collections: unordered collections, ordered collections and sorted collections. This picture shows the inheritance hierarchy for the primary collection classes. All primary collection classes derive from the abstract base class `TCollection`.



Ordered Collections (Sequences)

Sequences are collections that are externally ordered because they maintain internal elements according to the order in which they were added. The following sequences are available:

- `TList`
- `THashList`
- `TOrdCollection`
- `TObjArray`
- `TClonesArray`

The `TOrdCollection`, `TObjArray` as well as the `TClonesArray` can be sorted using their `Sort()` member function (if the stored items are sort able). Ordered collections all derive from the abstract base class `TSeqCollection`.

Sorted Collection

Sorted collections are ordered by an internal (automatic) sorting mechanism. The following sorted collections are available:

- `TSortedList`
- `TBtree`

The stored items must be sort able.

Unordered Collections

Unordered collections don't maintain the order in which the elements were added, i.e. when you iterate over an unordered collection, you are not likely to retrieve elements in the same order they were added to the collection. The following unordered collections are available:

- `THashTable`
- `TMap`

Iterators: Processing a Collection

The concept of processing all the members of a collection is generic, i.e. independent of any specific representation of a collection. To process each object in a collection one needs some type of cursor that is initialized and then steps over each member of the collection in turn. Collection objects could provide this service but there is a snag: as there is only one collection object per collection there would only be one cursor. Instead, to permit the use of as many cursors as required, they are made separate classes called iterators. For each collection class there is an associated iterator class that knows how to sequentially retrieve each member in turn. The relationship between a collection and its iterator is very close and may require that the iterator has full access to the collection (i.e. it is a friend class). In general iterators will be used via the **`TIter`** wrapper class.

For example:

- `TList` `TListIter`
- `TMap` `TMapIter`

Foundation Classes

All collections are based on the fundamental classes: `TCollection` and `TIterator`. They are so generic that it is not possible to create objects from them; they are only used as base classes for other classes (i.e. they are abstract base classes).

TCollection

The `TCollection` class provides the basic protocol (i.e. the minimum set of member functions) that all collection classes have to implement. These include:

- `Add()` Adds another object to the collection.
- `GetSize()` Returns the number of objects in the collection.
- `Clear()` Clears out the collection, but does not delete the removed objects.
- `Delete()` Clears out the collection and deletes the removed objects. This should only be used if the collection owns its objects (which is not normally the case).
- `FindObject()` Find an object given either its name or address.
- `MakeIterator()` Returns an iterator associated with the collection.
- `Remove()` Removes an object from the collection.

Coming back to the issue of object ownership. The code example below shows a class containing three lists, where the `fTracks` list is the owning collection and the other two lists are used to store a sub-set of the track objects. In the destructor of the class the `Delete()` method is called for the owning collection to delete correctly all its track objects.

```
class TEvent : public TObject {
private:
   TList *fTracks;  //list of all tracks
   TList *fVertex1; //subset of tracks part of vertex1
   TList *fVertex2; //subset of tracks part of vertex2
   ...
};

TEvent::~TEvent()
{
   fTracks->Delete(); delete fTracks;
   delete fVertex1; delete fVertex2;
}
```

TIterator

The `TIterator` class defines the minimum set of member functions that all iterators must support. These include:

- `Next()` return the next member of the collection or 0 if no more members.
- `Reset()` reset the iterator so that `Next()` returns the first object.

A Collectable Class

By default, all objects of `TObject` derived classes can be stored in ROOT containers. However, the `TObject` class provides some member functions that allow you to tune the behavior of objects in containers. For example, by default two objects are considered equal if their pointers point to the same address. This might be too strict for some classes where equality is already achieved if some or all of the data members are equal. By overriding the following `TObject` member functions, you can change the behavior of objects in collections:

- `IsEqual()` is used by the `FindObject()` collection method. By default, `IsEqual()` compares the two object pointers.
- `Compare()` returns –1, 0 or 1 depending if the object is smaller, equal or larger than the other object. By default, a `TObject` has not a valid `Compare()` method.
- `IsSortable()` returns true if the class is sort able (i.e. if it has a valid `Compare()` method). By default, a `TObject` is not sort able.
- `Hash()` returns a hash value. It needs to be implemented if an object has to be stored in a collection using a hashing technique, like `THashTable`, `THashList` and `TMap`. By default, `Hash()` returns the address of the object. It is essential to choose a good hash function.

The example below shows how to use and override these member functions.

```
// TObjNum is a simple container for an integer.
class TObjNum : public TObject {
private:
   int  num;

public:
   TObjNum(int i = 0) : num(i) { }
   ~TObjNum() { }
   void     SetNum(int i) { num = i; }
   int      GetNum() const { return num; }
   void     Print(Option_t *){ printf("num = %d\n", num); }
   Bool_t   IsEqual(TObject *obj)
              { return num == ((TObjNum*)obj)->num; }
   Bool_t   IsSortable() const { return kTRUE; }
   Int_t    Compare(TObject *obj)
              { if (num < ((TObjNum*)obj)->num)
                   return -1;
                else if (num > ((TObjNum*)obj)->num)
                   return 1;
                else
                   return 0; }
   ULong_t  Hash() { return num; }
};
```

The TIter Generic Iterator

As stated above, the `TIterator` class is abstract; it is not possible to create `TIterator` objects. However, it should be possible to write generic code to process all members of a collection so there is a need for a generic iterator object. A `TIter` object acts as generic iterator. It provides the same `Next()` and `Reset()` methods as `TIterator` although it has no idea how to support them! It works as follows:

- To create a `TIter` object its constructor must be passed an object that inherits from `TCollection`. The `TIter` constructor calls the `MakeIterator()` method of this collection to get the appropriate iterator object that inherits from `TIterator`.
- The `Next()` and `Reset()` methods of `TIter` simply call the `Next()` and `Reset()` methods of the iterator object.

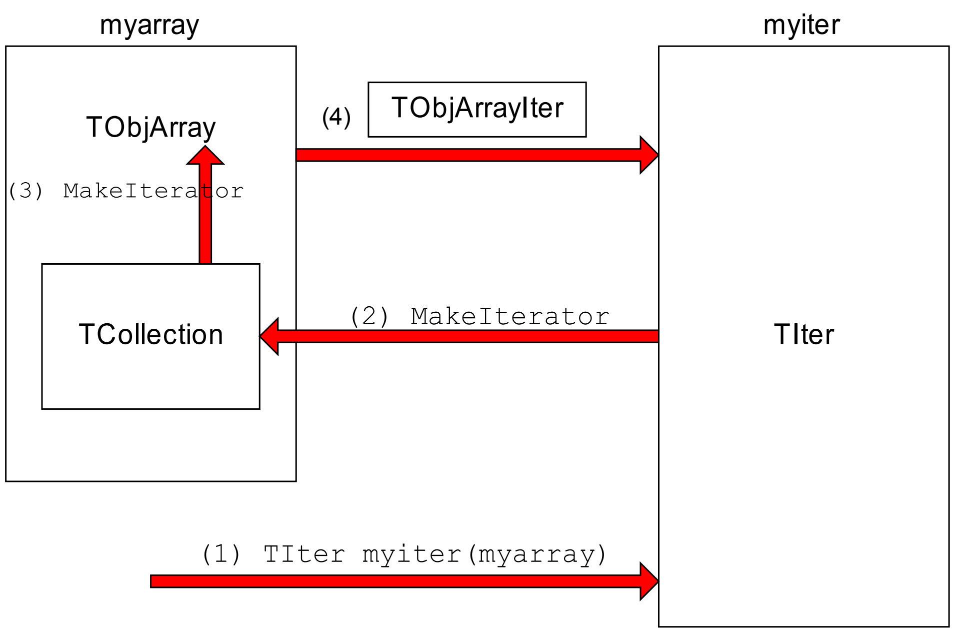
So `TIter` simply acts as a wrapper for an object of a concrete class inheriting from `TIterator`.

To see this working in practice, consider the `TObjArray` collection. Its associated iterator is `TObjArrayIter`. Suppose `myarray` is a pointer to a `TObjArray`, i.e.

```
TObjArray *myarray;
```

Which contains `MyClass` objects. To create a `TIter` object called `myiter`:

```
TIter myiter(myarray);
```



As shown in the diagram, this results in several methods being called:

(1) The `TIter` constructor is passed a `TObjArray`

(2) `TIter` asks embedded `TCollection` to make an iterator

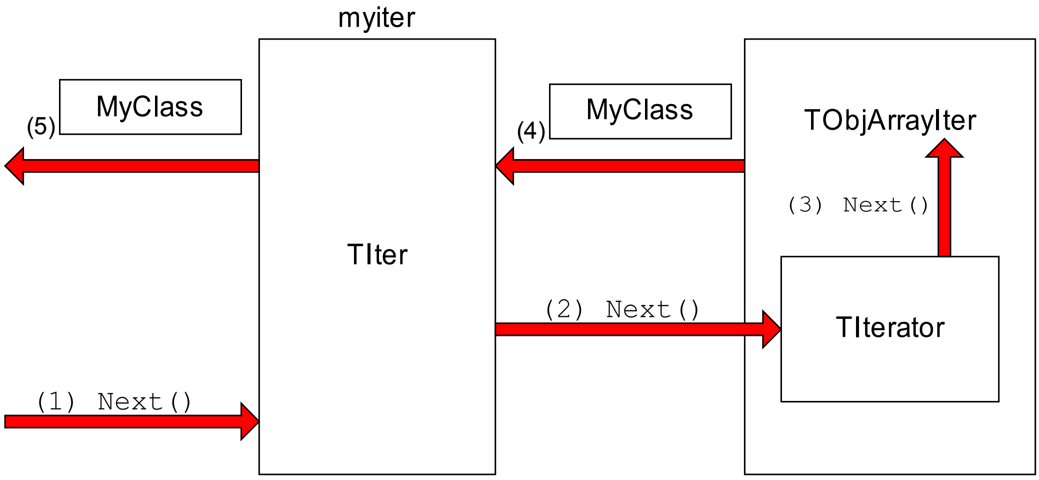
(3) `TCollection` asks `TObjArray` to make an iterator

(4) `TObjArray` returns a `TObjArrayIter`.

Now define a pointer for `MyClass` objects and set it to each member of the `TObjArray`:

```
MyClass *myobject;
while ((myobject = (MyClass *) myiter.Next())) {
   // process myobject
}
```

The heart of this is the `myiter.Next()` expression which does the



following:

(1) The `Next()` method of the `TIter` object `myiter` is called

(2) The `TIter` forwards the call to the `TIterator` embedded in the `TObjArrayIter`

(3) `TIterator` forwards the call to the `TObjArrayIter`

(4) `TObjArrayIter` finds the next `MyClass` object and returns it

(5) `TIter` passes the `MyClass` object back to the caller

Sometimes the `TIter` object is called `next`, and then instead of writing:

`next.Next()`

Which is legal, but looks rather odd, iteration is written as:

`next()`

This works because the function `operator()` is defined for the `TIter` class to be equivalent to the `Next()` method.

The TList Collection

A `TList` is a doubly linked list. Before being inserted into the list the object pointer is wrapped in a `TObjLink` object that contains, besides the object pointer also a previous and next pointer.

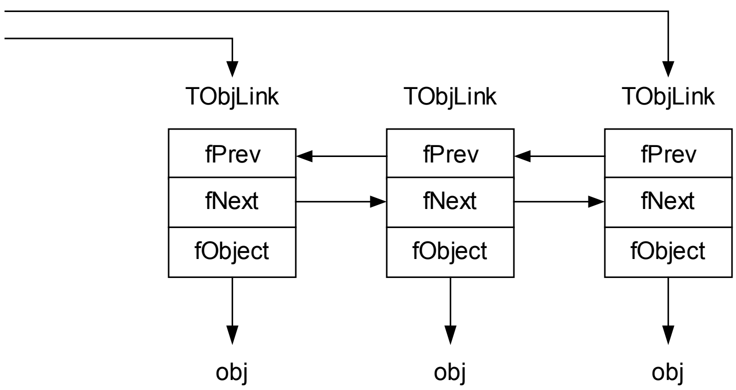
Objects are typically added using:

- `Add()`
- `AddFirst()`, `AddLast()`
- `AddBefore()`, `AddAfter()`

Main features of `TList`: very low cost of adding/removing elements anywhere in the list.

Overhead per element: 1 `TObjLink`, i.e. two 4 (or 8) byte pointers + pointer to `vtable` = 12 (or 24) bytes.

```
class TList : public TSeqCollection
{
private:
  TObjLink  *fLast;
  TObjLink *fFirst;
  . . .
  . . .
};

class TObjLink {
friend class TList;
private:
  TObjLink *fPrev;
  TObjLink *fNext;
  TObject   *fObject;
  . . .
  . . .
};
```



The diagram below shows the internal data structure of a `TList`:

Iterating over a TList

There are basically four ways to iterate over a `TList`:

(1) Using the **`ForEach`** script:

```
GetListOfPrimitives()->ForEach(TObject,Draw)();
```

(2) Using the `TList` iterator **`TListIter`** (via the wrapper class **`TIter`**):

```
TIter next(GetListOfTracks());
while ((TTrack *obj = (TTrack *)next()))
   obj->Draw();
```

(3) Using the **`TObjLink`** list entries (that wrap the `TObject*`):

```
TObjLink *lnk = GetListOfPrimitives()->FirstLink();
while (lnk) {
   lnk->GetObject()->Draw();
   lnk = lnk->Next();
}
```

(4) Using the `TList's` **`After()`** and **`Before()`** member functions:

```
TFree *idcur = this;
while (idcur) {
   ...
   ...
   idcur = (TFree*)GetListOfFree()->After(idcur);
}
```

Method 1 uses internally method 2.

Method 2 works for all collection classes. `TIter` overloads `operator()`.

Methods 3 and 4 are specific for `TList`.

Methods 2, 3 and 4 can also easily iterate backwards using either a backward `TIter` (using argument `kIterBackward`) or by using `LastLink()` and `lnk->Prev()` or by using the `Before()` method.

The TObjArray Collection

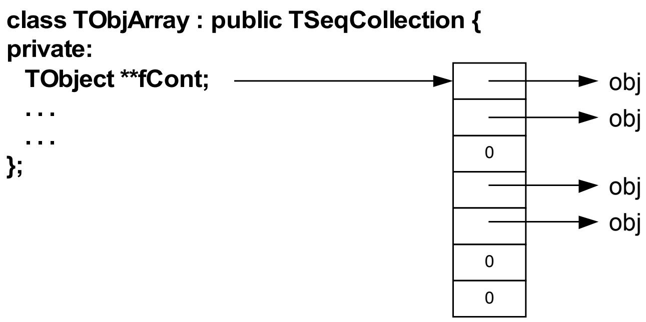
A `TObjArray` is a collection which supports traditional array semantics via the overloading of `operator[]`. Objects can be directly accessed via an index. The array expands automatically when objects are added.

At creation time one specifies the default array size (default = 16) and lower bound (default = 0). Resizing involves a re-allocation and a copy of the old array to the new. This can be costly if done too often. If possible, set initial size close to expected final size. Index validity is always checked (if you are 100% sure and maximum performance is needed you can use `UnCheckedAt()` instead of `At()` or `operator[]`).

If the stored objects are sort able the array can be sorted using `Sort()`. Once sorted, efficient searching is possible via the `BinarySearch()` method.

Iterating can be done using a `TIter` iterator or via a simple for loop:

```
for (int i = 0; i <= fArr.GetLast(); i++)
   if ((track = (TTrack*)fArr[i]))      // or fArr.At(i)
      track->Draw();
```



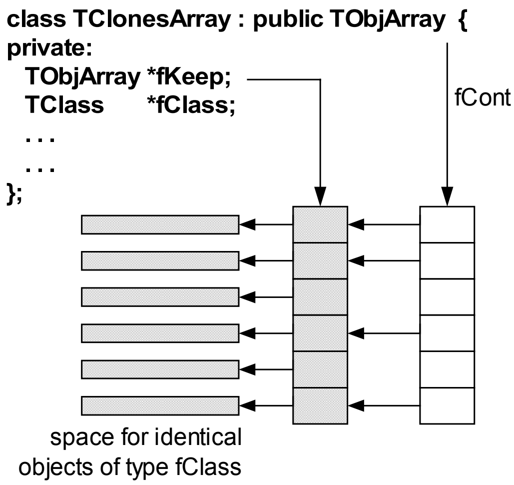
Main features of `TObjArray`: simple, well known array semantics.

Overhead per element: none, except possible over sizing of `fCont`.

The diagram below shows the internal data structure of a `TObjArray`:

TClonesArray – An Array of Identical Objects

A `TClonesArray` is an array of identical (clone) objects. The memory for the objects stored in the array is allocated only once in the lifetime of the clones array. All objects must be of the same class and the object must have a fixed size (i.e. they may not allocate other objects). For the rest this class has the



same properties as a `TObjArray`.

The class is specially designed for repetitive data analysis tasks, where in a loop many times the same objects are created and deleted.

The diagram below shows the internal data structure of a `TClonesArray`:

The Idea Behind TClonesArray

To reduce the very large number of new and delete calls in large loops like this (O(100000) x O(10000) times new/delete):

```
TObjArray a(10000);
while (TEvent *ev = (TEvent *)next()) {     // O(100000)
   for (int i = 0; i < ev->Ntracks; i++) { // O(10000)
      a[i] = new TTrack(x,y,z,...);
      ...
      ...
   }
   ...
   a.Delete();
}
```

You better use a TClonesArray which reduces the number of new/delete calls to only O(10000):

```
TClonesArray a("TTrack", 10000);
while (TEvent *ev = (TEvent *)next()) {        // O(100000)
   for (int i = 0; i < ev->Ntracks; i++) {    // O(10000)
      new(a[i]) TTrack(x,y,z,...);
      ...
      ...
   }
   ...
   a.Delete();
}
```

Considering that a pair of new/delete calls on average cost about 70 μs, O(10^9) new/deletes will save about 19 hours.

For the other collections see the class reference guide on the web and the test program `$ROOTSYS/test/tcollex.cxx`.

Template Containers and STL

Some people dislike polymorphic containers because they are not truly "type safe". In the end, the compiler leaves it the user to ensure that the types are correct. This only leaves the other alternative: creating a new class each time a new (container organization) / (contained object) combination is needed. To say the least this could be very tedious. Most people faced with this choice would, for each type of container:

1. Define the class leaving a dummy name for the contained object type.
2. When a particular container was needed, copy the code and then do a global search and replace for the contained class.

C++ has a built in template scheme that effectively does just this. For example:

```
template<class T>

class ArrayContainer {
private:
  T *member[10];
...
};
```

This is an array container with a 10-element array of pointers to `T`, it could hold up to 10 `T` objects. This array is flawed because it is static and hard-coded, it should be dynamic. However, the important point is that the template statement indicates that `T` is a template, or parameterized class. If we need an `ArrayContainer` for `Track` objects, it can be created by:

```
ArrayContainer<Track> MyTrackArrayContainer;
```

C++ takes the parameter list, and substitutes `Track` for `T` throughout the definition of the class `ArrayContainer`, then compiles the code so generated, effectively doing the same we could do by hand, but with a lot less effort. This produces code that is type safe, but does have different drawbacks:

- Templates make code harder to read.

- At the time of writing this documentation, some compilers can be very slow when dealing with templates.
- It does not solve the problem when a container has to hold a heterogeneous set of objects.
- The system can end up generating a great deal of code; each container/object combination has its own code, a phenomenon that is sometimes referred to as *code bloat*.

The Standard Template Library (STL) is part on ANSI C++, and includes a set of template containers.

13 Physics Vectors

The physics vector classes describe vectors in three and four dimensions and their rotation algorithms. The classes were ported to root from CLHEP see:
http://wwwinfo.cern.ch/asd/lhc++/clhep/manual/UserGuide/Vector/vector.html

The Physics Vector Classes

There are four classes in this package. They are:

`TVector3`: A general tree-vector. A `TVector3` may be expressed in Cartesian, polar, or cylindrical coordinates. Methods include dot and cross products, unit vectors and magnitudes, angles between vectors, and rotations and boosts. There are also functions of particular use to HEP, like pseudo-rapidity, projections, and transverse part of a `TVector3`, and kinetic methods on 4-vectors such as `Invariant Mass of pairs or containers of particles.`

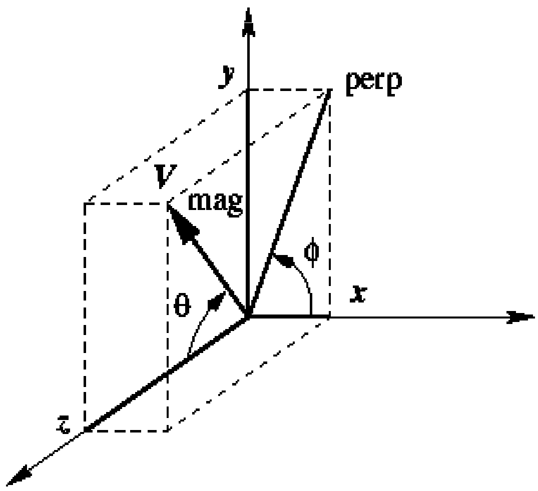
`TLorenzVector`: a general four-vector class, which can be used either for the description of position and time (`x, y, z, t`) or momentum and energy (`px, py, pz, E`).

`TRotation`: a class describing a rotation of a `TVector3` object.

`TLorenzRotation`: a class to describe the Lorentz transformations including Lorentz boosts and rotations.

There is also a TVector2, it is a basic implementation of a vector in two dimensions and not part of the CLHEP translation.

TVector3



`TVector3` is a general three vector class, which can be used for description of different vectors in 3D. Components of three vector:

x ,y ,z - basic components
θ = azimuth angle
ϕ = polar angle
magnitude = mag = sqrt(x^2 + y^2 + z^2)
transverse component = perp = sqrt(x^2 + y^2)

Using the `TVector3` class you should remember that it contains only common features of three vectors and lacks methods specific for some particular vector values. For example, it has no translate function because translation has no meaning for vectors.

Declaration / Access to the components

`TVector3` has been implemented as a vector of three `Double_t` variables, representing the Cartesian coordinates. By default the values are initialized to zero, however you can change them in the constructor:

```
TVector3 v1;         // v1 = (0,0,0)
TVector3 v2(1);      // v2 = (1,0,0)
TVector3 v3(1,2,3); // v3 = (1,2,3)
TVector3 v4(v2);     // v4 = v2
```

It is also possible (but not recommended) to initialize a `TVector3` with a `Double_t` or `Float_t C` array.

You can get the components by name or by index:

```
xx = v1.X();    or    xx = v1(0);
yy = v1.Y();          yy = v1(1);
zz = v1.Z();          zz = v1(2);
```

The methods SetX(), SetY(), SetZ() and SetXYZ() allows you to set the components:

```
v1.SetX(1.); v1.SetY(2.); v1.SetZ(3.);
v1.SetXYZ(1.,2.,3.);
```

Other Coordinates

To get information on the TVector3 in spherical (rho, phi, theta) or cylindrical (z, r, theta) coordinates, the following methods can be used.

```
Double_t m  = v.Mag();
// get magnitude (=rho=Sqrt(x*x+y*y+z*z)))
Double_t m2 = v.Mag2();     // get magnitude squared
Double_t t  = v.Theta();    // get polar angle
Double_t ct = v.CosTheta();// get cos of theta
Double_t p  = v.Phi();      // get azimuth angle
Double_t pp = v.Perp();     // get transverse component
Double_t pp2= v.Perp2();    // get transverse squared
```

It is also possible to get the transverse component with respect to another vector:

```
Double_t ppv1  = v.Perp(v1);
Double_t pp2v1 = v.Perp2(v1);
```

The pseudo-rapidity (eta = -ln (tan (phi/2))) can be get by Eta() or PseudoRapidity():

```
Double_t eta = v.PseudoRapidity();
```

These setters change one of the non-Cartesian coordinates:

```
v.SetTheta(.5);   // keeping rho and phi
v.SetPhi(.8);     // keeping rho and theta
v.SetMag(10.);    // keeping theta and phi
v.SetPerp(3.);    // keeping z and phi
```

Arithmetic / Comparison

The TVector3 class has operators to add, subtract, scale and compare vectors:

```
v3  = -v1;
v1  = v2+v3;
v1 += v3;
v1  = v1 - v3
v1 -= v3;
v1 *= 10;
v1  = 5*v2;
if(v1 == v2) {...}
if(v1 != v2) {...}
```

Related Vectors

```
v2 = v1.Unit();          // get unit vector parallel to v1
v2 = v1.Orthogonal();   // get vector orthogonal to v1
```

Scalar and Vector Products

```
s = v1.Dot(v2);    // scalar product
s = v1 * v2;       // scalar product
v = v1.Cross(v2); // vector product
```

Angle between Two Vectors

```
Double_t a = v1.Angle(v2);
```

Rotation around Axes

```
v.RotateX(.5);
v.RotateY(TMath::Pi());
v.RotateZ(angle);
```

Rotation around a Vector

```
v1.Rotate(TMath::Pi()/4, v2); // rotation around v2
```

Rotation by TRotation

`TVector3` objects can be rotated by `TRotation` objects using the `Transform()` method, the `operator *=`, or the `operator *` of the `TRotation` class. See the later section on `TRotation`.

```
TRotation m;
...
v1.transform(m);
v1 = m*v1;
v1 *= m;                          // v1 = m*v1
```

Transformation from Rotated Frame

This code transforms `v1` from the rotated frame (`z'` parallel to direction, `x'` in the theta plane and `y'` in the `xy` plane as well as perpendicular to the theta plane) to the (x, y, z) frame.

```
TVector3 direction = v.Unit()
v1.RotateUz(direction);
// direction must be TVector3 of unit length
```

TRotation

The `TRotation` class describes a rotation of `TVector3` object. It is a 3 * 3 matrix of `Double_t`:

```
| xx  xy  xz |
| yx  yy  yz |
| zx  zy  zz |
```

It describes a so-called active rotation, i.e. a rotation of objects inside a static system of coordinates. In case you want to rotate the frame and want to know the coordinates of objects in the rotated system, you should apply the inverse rotation to the objects. If you want to transform coordinates from the rotated frame to the original frame you have to apply the direct transformation.

A rotation around a specified axis means counterclockwise rotation around the positive direction of the axis.

Declaration, Access, Comparisons

```
TRotation r;    // r initialized as identity
TRotation m(r); // m = r
```

There is no direct way to set the matrix elements - to ensure that a `TRotation` always describes a real rotation. But you can get the values by with the methods `XX()..ZZ()` or the `(,)` operator:

```
Double_t xx = r.XX();      //  the same as xx=r(0,0)
         xx = r(0,0);
if (r==m) {...}            // test for equality
if (r!=m) {..}             // test for inequality
if (r.IsIdentity()) {...} // test for identity
```

Rotation Around Axes

The following matrices describe counter-clockwise rotations around the coordinate axes and are implemented in: `RotateX()`, `RotateY()` and `RotateZ()`:

```
        | 1   0       0    |
Rx(a) = | 1 cos(a)  -sin(a) |
        | 0 sin(a)  cos(a)  |


        | cos(a)  0 sin(a) |
Ry(a) = |   0     1   0    |
        | -sin(a) 0 cos(a) |


        | cos(a) -sin(a) 0 |
Rz(a) = | cos(a) -sin(a) 0 |
        |   0      0     1 |
```

```
r.RotateX(TMath::Pi()); // rotation around the x-axis
```

Rotation around Arbitrary Axis

The `Rotate()` method allows you to rotate around an arbitrary vector (not necessary a unit one) and returns the result.

```
r.Rotate(TMath::Pi()/3,TVector3(3,4,5));
```

It is possible to find a unit vector and an angle, which describe the same rotation as the current one:

```
Double_t angle;
TVector3 axis;
r.GetAngleAxis(angle,axis);
```

Rotation of Local Axes

The `RotateAxes()method` adds a rotation of local axes to the current rotation and returns the result:

```
  TVector3 newX(0,1,0);
  TVector3 newY(0,0,1);
  TVector3 newZ(1,0,0);
  a.RotateAxes(newX,newX,newZ);
```

Methods `ThetaX(), ThetaY(), ThetaZ(), PhiX(), PhiY(),PhiZ()` return azimuth and polar angles of the rotated axes:

```
  Double_t tx,ty,tz,px,py,pz;
  tx= a.ThetaX();
  ...
  pz= a.PhiZ();
```

Inverse Rotation

```
  TRotation a,b;
  ...
  b = a.Inverse();  // b is inverse of a, a is unchanged
  b = a.Invert();   // invert a and set b = a
```

Compound Rotations

The `operator *` has been implemented in a way that follows the mathematical notation of a product of the two matrices which describe the two consecutive rotations. Therefore the second rotation should be placed first:

```
r = r2 * r1;
```

Rotation of TVector3

The TRotation class provides an operator * which allows to express a rotation of a TVector3 analog to the mathematical notation

```
| x' |   | xx xy xz | | x |
| y' | = | yx yy yz | | y |
| z' |   | zx zy zz | | z |
```

```
TRotation r;
TVector3 v(1,1,1);
v = r * v;
```

You can also use the Transform() method or the operator *= of the TVector3 class:

```
TVector3 v;
TRotation r;
v.Transform(r);
```

TLorentzVector

`TLorentzVector` is a general four-vector class, which can be used either for the description of position and time (`x, y, z, t`) or momentum and energy (`px, py, pz, E`).

Declaration

`TLorentzVector` has been implemented as a set a `TVector3` and a `Double_t` variable. By default all components are initialized by zero.

```
  TLorentzVector v1;      // initialized by (0., 0., 0.,
0.)
  TLorentzVector v2(1., 1., 1., 1.);
  TLorentzVector v3(v1);
  TLorentzVector v4(TVector3(1., 2., 3.),4.);
```

For backward compatibility there are two constructors from a `Double_t` and `Float_t` C array.

Access to Components

There are two sets of access functions to the components of a `LorentzVector`: `X(), Y(), Z(), T()` and `Px(), Py(), Pz() and E()`. Both sets return the same values but the first set is more relevant for use where `TLorentzVector` describes a combination of position and time and the second set is more relevant where `TLorentzVector` describes momentum and energy:

```
  Double_t xx =v.X();
  ...
  Double_t tt = v.T();
  Double_t px = v.Px();
  ...
  Double_t ee = v.E();
```

The components of TLorentzVector can also accessed by index: |

```
  xx = v(0);       or     xx = v[0];
  yy = v(1);              yy = v[1];
  zz = v(2);              zz = v[2];
  tt = v(3);              tt = v[3];
```

You can use the `Vect()` method to get the vector component of `TLorentzVector`:

```
  TVector3 p = v.Vect();
```

For setting components there are two methods: `SetX(),..,` `SetPx(),..:`

```
v.SetX(1.);        or    v.SetPx(1.);
...                           ...
v.SetT(1.);              v.SetE(1.);
```

To set more the one component by one call you can use the `SetVect()` function for the `TVector3` part or `SetXYZT()`, `SetPxPyPzE()`. For convenience there is also a `SetXYZM()`:

```
v.SetVect(TVector3(1,2,3));
v.SetXYZT(x,y,z,t);
v.SetPxPyPzE(px,py,pz,e);
v.SetXYZM(x,y,z,m);
// v=(x,y,z,e=Sqrt(x*x+y*y+z*z+m*m))
```

Vector Components in non-Cartesian Coordinates

There are a couple of methods to get and set the `TVector3` part of the parameters in **spherical** coordinate systems:

```
Double_t m, theta, cost, phi, pp, pp2, ppv2, pp2v2;
m = v.Rho();
t = v.Theta();
cost = v.CosTheta();
phi = v.Phi();
v.SetRho(10.);
v.SetTheta(TMath::Pi()*.3);
v.SetPhi(TMath::Pi());
```

or get information about the r-coordinate in cylindrical systems:

```
Double_t pp, pp2, ppv2, pp2v2;
pp   = v.Perp();        // get transvers component
pp2  = v.Perp2();       // get transverse component squared
ppv2 = v.Perp(v1);      // get transvers component with
                        // respect to another vector
pp2v2 = v.Perp(v1);
```

for convenience there are two more set functions `SetPtEtaPhiE(pt,eta,phi,e); and` `SetPtEtaPhiM(pt,eta,phi,m);`

Arithmetic and Comparison Operators

The `TLorentzVector` class provides operators to add, subtract or compare four-vectors:

```
v3 = -v1;
v1 = v2+v3;
v1+= v3;
v1 = v2 + v3;
v1-= v3;
if (v1 == v2) {...}
if(v1 != v3) {...}
```

Magnitude/Invariant mass, beta, gamma, scalar product

The scalar product of two four-vectors is calculated with the (-,-,-,+) metric:

s = v1*v2 = `t1*t2-x1*x2-y1*y2-z1*z2`

The magnitude squared `mag2` of a four-vector is therefore:

mag2 = v*v = `t*t-x*x-y*y-z*z`

If `mag2` is negative `mag = -Sqrt(-mag*mag)`.

The methods are:

```
Double_t s, s2;
s  = v1.Dot(v2);         // scalar product
s  = v1*v2;              // scalar product
s2 = v.Mag2();   or      s2 = v.M2();
s  = v.Mag();            s  = v.M();
```

Since in case of momentum and energy the magnitude has the meaning of invariant mass `TLorentzVector` provides the more meaningful aliases `M2()` and `M();`

The methods `Beta()` and `Gamma()` returns `beta` and `gamma = 1/Sqrt(1-beta*beta)`.

Lorentz Boost

A boost in a general direction can be parameterized with three parameters which can be taken as the components of a three vector **b** `= (bx,by,bz)`. With

`x = (x,y,z) and gamma = 1/Sqrt(1-beta*beta)`, an arbitrary active Lorentz boost transformation (from the rod frame to the original frame) can be written as:

```
x = x' + (gamma-1)/(beta*beta)*(b*x') * b + gamma * t'* b
t = gamma (t'+ b*x).
```

The `Boost()method` performs a boost transformation from the rod frame to the original frame. `BoostVector()` returns a `TVector3` of the spatial components divided by the time component:

```
TVector3 b;
v.Boost(bx,by,bz);
v.Boost(b);
b = v.BoostVector();    // b=(x/t,y/t,z/t)
```

Rotations

There are four sets of functions to rotate the `TVector3` component of a `TLorentzVector`:

Rotation around Axes

```
v.RotateX(TMath::Pi()/2.);
v.RotateY(.5);
v.RotateZ(.99);
```

Rotation around an Arbitrary Axis

```
v.Rotate(TMath::Pi()/4., v1); // rotation around v1
```

Transformation from Rotated Frame

```
v.RotateUz(direction); // direction must be a unit TVector3
```

by TRotation (see TRotation)

```
TRotation r;
v.Transform(r);    or     v *= r; // v = r*v
```

Miscellaneous

Angle Between Two Vectors

```
Double_t a = v1.Angle(v2);  // get angle between v1 and v2
```

Light-cone Components

Methods `Plus()` and `Minus()` return the positive and negative light-cone components:

```
Double_t pcone = v.Plus();
Double_t mcone = v.Minus();
```

Transformation by TLorentzRotation

A general Lorentz transformation see class `TLorentzRotation` can be used by the `Transform()` method, the `*=, or *` operator of the `TLorentzRotation` class:

```
TLorentzRotation l;
v.Transform(l);
v = l*v;     or     v *= l;  // v = l*v
```

TLorentzRotation

The `TLorentzRotation` class describes Lorentz transformations including Lorentz boosts and rotations (see `TRotation`)

```
             | xx  xy  xz  xt |
             |                |
             | yx  yy  yz  yt |
    lambda = |                |
             | zx  zy  zz  zt |
             |                |
             | tx  ty  tz  tt |
```

Declaration

By default it is initialized to the identity matrix, but it may also be initialized by an other `TLorentzRotation`, by a pure `TRotation` or by a boost:

```
TLorentzRotation l;      // l is initialized as identity
TLorentzRotation m(l);   // m = l
TRotation r;
TLorentzRotation lr(r);
TLorentzRotation lb1(bx,by,bz);
TVector3 b;
TLorentzRotation lb2(b);
```

The Matrix for a Lorentz boosts is:

```
| 1+gamma'*bx*bx  gamma'*bx*by   gamma'*bx*bz  gamma*bx |
|  gamma'*bx*bz  1+gamma'*by*by  gamma'*by*by  gamma*by |
|  gamma'*bz*bx   gamma'*bz*by  1+gamma'*bz*bz gamma*bz |
|    gamma*bx       gamma*by       gamma*bz     gamma   |
```

with the boost vector `b=(bx,by,bz)` and `gamma=1/Sqrt(1-beta*beta)` and `gamma'=(gamma-1)/beta*beta.`

Access to the matrix Components/Comparisons

Access to the matrix components is possible with the methods `XX()`, `XY()` `.. TT()`, `and` with the `operator (int,int)`:

```
  Double_t xx;
  TLorentzRotation l;
  xx = l.XX();                 // gets the xx component
  xx = l(0,0);                 // gets the xx component
  if (l==m) {...}              // test for equality
  if (l !=m) {...}             // test for inequality
  if (l.IsIdentity()) {...} // test for identity
```

Transformations of a Lorentz Rotation

Compound transformations

There are four possibilities to find the product of two `TLorentzRotation` transformations:

```
  TLorentzRotation a,b,c;
  c = b*a;                           // product
  c = a.MatrixMultiplication(b);  // a is unchanged
  a *= b;                            // a=a*b
  c = a.Transform(b)                 // a=b*a then c=a
```

Lorentz boosts

```
  Double_t bx, by, bz;
  TVector3 v(bx,by,bz);
  TLorentzRotation l;
  l.Boost(v);
  l.Boost(bx,by,bz);
```

Rotations

```
  TVector3 axis;
  l.RotateX(TMath::Pi());    //  rotation around x-axis
  l.Rotate(.5,axis);         //  rotation around specified
vector
```

Inverse transformation

The matrix for the inverse transformation of a `TLorentzRotation` is as follows:

```
| xx  yx  zx -tx |
|                |
| xy  yy  zy -ty |
|                |
| xz  yz  zz -tz |
|                |
|-xt -yt -zt  tt |
```

To return the inverse transformation keeping the current one unchanged, use the method `Inverse()`. `Invert()` inverts the current

`TLorentzRotation`:

```
l1 = l2.Inverse();  // l1 is inverse of l2, l2 unchanged
l1 = l2.Invert();   // invert l2, then  l1=l2
```

Transformation of a TLorentzVector

To apply `TLorentzRotation` to `TLorentzVector` you can use either the `VectorMultiplication()` method or the `* operator`. You can also use the `Transform()` function and the `*=` operator of the `TLorentzVector` class.

```
TLorentzVector v;
TLorentzVector l;
...
v=l.VectorMultiplication(v);
v = l * v;
v.Transform(l);
v *= l;  // v = l*v
```

Physics Vector Example

To see an example of using physics vectors you can look at the test file. It is in `$ROOTSYS/test/TestVectors.cxx`. The vector classes are not loaded by default, and to run it, you will need to load `libPhysics.so` first:

```
root [] .L $ROOTSYS/lib/libPhysics.so
root [] .x TestVectors.cxx
```

To load the physics vector library in a ROOT application use:

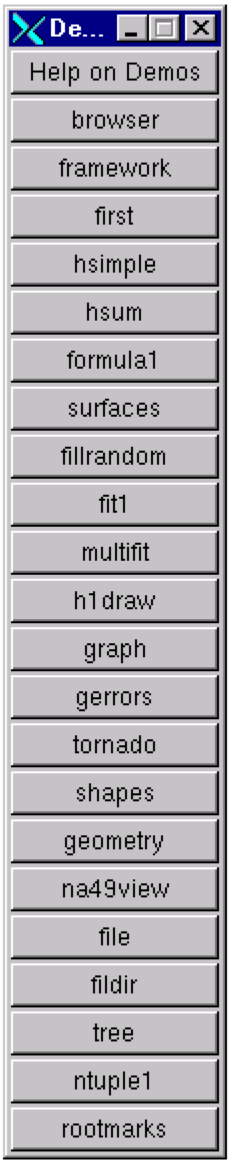
```
gSystem->Load("libPhysics");
```

The example `$ROOTSYS/test/TestVectors.cxx` does not return much, especially if all went well, but when you look at the code you will find examples for many calls.

14 The Tutorials and Tests

This chapter is a guide to the examples that come with the installation of ROOT. They are located in two directories: `$ROOTSYS/tutorials` and `$ROOTSYS/test`.

$ROOTSYS/tutorials



The tutorials directory contains many example scripts. For the examples to work you must have write permission and you will need to execute `hsimple.C` first. If you do not have write permission in the $ROOTSYS/tutorials directory, copy the entire directory to your area.

The script `hsimple.C` displays a histogram as it is being filled, and creates a ROOT file used by the other examples. To execute it type:

```
> cd $ROOTSYS/tutorials
> root
  *******************************************
  *                                         *
  *        W E L C O M E  to  R O O T       *
  *                                         *
  *   Version   2.25/02      21 August 2000 *
  *                                         *
  *  You are welcome to visit our Web site  *
  *          http://root.cern.ch            *
  *                                         *
  *******************************************

CINT/ROOT C/C++ Interpreter version 5.14.47, Aug 12 2000
Type ? for help. Commands must be C++ statements.
Enclose multiple statements between { }.

Welcome to the ROOT tutorials


Type ".x demos.C" to get a toolbar from which to execute
the demos

Type ".x demoshelp.C" to see the help window

root [] .x hsimple.C
hsimple: Real Time =5.42 seconds Cpu Time = 3.92 seconds
```

Now execute `demos.C`, which brings up the button bar shown on the left. You can click on any button to execute an other example. To see the source, open the corresponding source file (for example `fit1.C`). Once you are done, and want to quit the ROOT session, you can do so by typing .q.

```
root [] .x demos.C
…
root [] .q
```

$ROOTSYS/test

The test directory contains a set of examples that represent all areas of the framework. When a new release is cut, the examples in this directory are compiled and run to test the new release's backward compatibility.

We see these source files:

- `hsimple.cxx` - Simple test program that creates and saves some histograms
- `MainEvent.cxx` - Simple test program that creates a ROOT Tree object and fills it with some simple structures but also with complete histograms. This program uses the files `Event.cxx`, `EventCint.cxx` and `Event.h`. An example of a procedure to link this program is in `bind_Event`. Note that the `Makefile` invokes the rootcint utility to generate the CINT interface `EventCint.cxx`.
- `Event.cxx` - Implementation for classes Event and Track
- `minexam.cxx` - Simple test program to test data fitting.
- `tcollex.cxx` - Example usage of the ROOT collection classes.
- `tcollbm.cxx` - Benchmarks of ROOT collection classes
- `tstring.cxx` - Example usage of the ROOT string class.
- `vmatrix.cxx` - Verification program for the `TMatrix` class.
- `vvector.cxx` - Verification program for the `TVector` class.
- `vlazy.cxx` - Verification program for lazy matrices. .
- `hworld.cxx` - Small program showing basic graphics. .
- `guitest.cxx` - Example usage of the ROOT GUI classes.
- `Hello.cxx` - Dancing text example
- `Aclock.cxx` - Analog clock (a la X11 `xclock`)
- `Tetris.cxx` - The famous Tetris game (using ROOT basic graphics) .
- `stress.cxx` - Important ROOT stress testing program.

The `$ROOTSYS/test` directory is a gold mine of root-wisdom nuggets, and we encourage you to explore and exploit it. These instructions will compile all programs in `$ROOTSYS/test`:

1. If you do not have write permission in the `$ROOTSYS/test` directory, copy the entire `$ROOTSYS/test` directory to your area.

2. The `Makefile` is a useful example of how ROOT applications are linked and built. Edit the `Makefile` to specify your architecture by changing the `ARCH` variable, for example, on an SGI machine type:

```
ARCH = sgikcc
```

3. Now compile all programs:

```
% gmake
```

This will build several applications and shared libraries. We are especially interested in `Event`, `stress`, and `guitest`.

Event – An Example of a ROOT Application .

`Event` is created by compiling `MainEvent.cxx`, and `Event.cxx`. It creates a ROOT file with a tree and two histograms.

When running `Event` we have four optional arguments with defaults:

	Argument	Default
1	**Number of Events** (1 ... n)	400
2	**Compression level:** 0: no compression at all. 1: If the split level is set to zero, everything is compressed according to the gzip level 1. If split level is set to 1, leaves that are not floating point numbers are compressed using the gzip level 1. 2: If the split level is set to zero, everything is compressed according to the gzip level 2. If split level is set to 1, all non floating point leaves are compressed according to the gzip level 2 and the floating point leaves are compressed according to the gzip level 1 (gzip level –1). Floating point numbers are compressed differently because the gain when compressing them is about 20 - 30%. For other data types it is generally better and around 100%.	1
3	**Split or not Split** 0: only one single branch is created and the complete event is serialized in one single buffer 1: a branch per variable is created.	1 (Split)
4	**Fill** 0: read the file 1: write the file, but don't fill the histograms 2: don't write, don’t fill the histograms 10: fill the histograms, don't write the file 11: fill the histograms, write the file 20: read the file sequentially 25: read the file at random	1 (Write, no fill)

Effect of Compression on File Size and Write Times

You may have noticed that a ROOT file has up to nine compression level, but here only levels 0, 1, and 2 are described. Compression levels above 2 are not competitive. They take up to much write time compared to the gain in file space.

Below are three runs of `Event` on a Pentium III 650 Mhz and the resulting file size and write and read times.

<u>*No Compression:*</u>

```
> Event 400 0 1 1
400 events and 19153182 bytes processed.
RealTime=6.840000 seconds, CpuTime=3.560000 seconds
compression level=0, split=1, arg4=1
You write 2.800173 Mbytes/Realtime seconds
You write 5.380107 Mbytes/Cputime seconds

> ls -l Event.root
… 19752171 Feb 23 18:26 Event.root

> Event 400 0 1 20
400 events and 19153182 bytes processed.
RealTime=0.790000 seconds, CpuTime=0.790000 seconds
You read 24.244533 Mbytes/Realtime seconds
You read 24.244533 Mbytes/Cputime seconds
```

We see the file size without compression is 19.75 MB, the write time is 6.84 seconds and the read time is 0.79 seconds.

<u>*Compression = 1: event is compressed*</u>:

```
> Event 400 1 1 1
400 events and 19153182 bytes processed.
RealTime=6.440000 seconds, CpuTime=4.020000 seconds
compression level=1, split=1, arg4=1
You write 2.974096 Mbytes/Realtime seconds
You write 4.764473 Mbytes/Cputime seconds

> ls -l Event.root
…     17728188 Feb 23 18:28 Event.root

> Event 400 1 1 20
400 events and 19153182 bytes processed.
RealTime=0.900000 seconds, CpuTime=0.900000 seconds
You read 21.281312 Mbytes/Realtime seconds
You read 21.281312 Mbytes/Cputime seconds
```

We see the file size 17.73, the write time was 6.44 seconds and the read time was 0.9 seconds.

Compression = 2: Floating point numbers are compressed with level 1:

```
> Event 400 2 1 1
400 events and 19153182 bytes processed.
RealTime=11.340000 seconds, CpuTime=9.510000 seconds
compression level=2, split=1, arg4=1
You write 1.688993 Mbytes/Realtime seconds
You write 2.014004 Mbytes/Cputime seconds

> ls -l Event.root
…     13783799 Feb 23 18:29 Event.root

> Event 400 2 1 20
400 events and 19153182 bytes processed.
RealTime=2.170000 seconds, CpuTime=2.170000 seconds
You read 8.826351 Mbytes/Realtime seconds
You read 8.826351 Mbytes/Cputime seconds
```

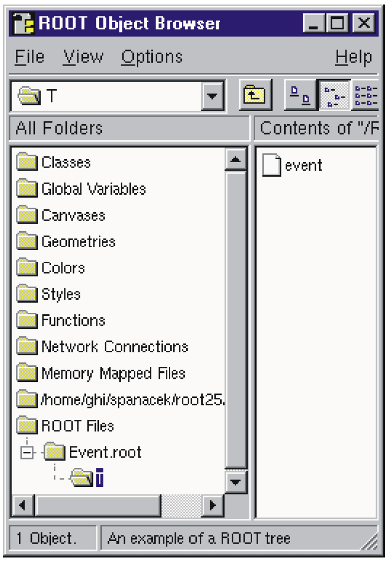
The file size is 13.78 MB, the write time is 11.34 seconds and the read time is 2.17 seconds.

This table summarizes the findings on the impact of compressions:

Compression	File Size	Write Times	Read Times
0	19.75 MB	6.84 sec.	0.79 sec.
1	17.73 MB	6.44 sec.	0.90 sec.
2	13.78 MB	11.34 sec.	2.17 sec.

Setting the Split Level

Split Level = 0:



Now we execute Event with the split parameter set to 0:

```
> Event 400 1 0 1
> root
root [] TFile f("Event.root")
root [] TBrowser T
```

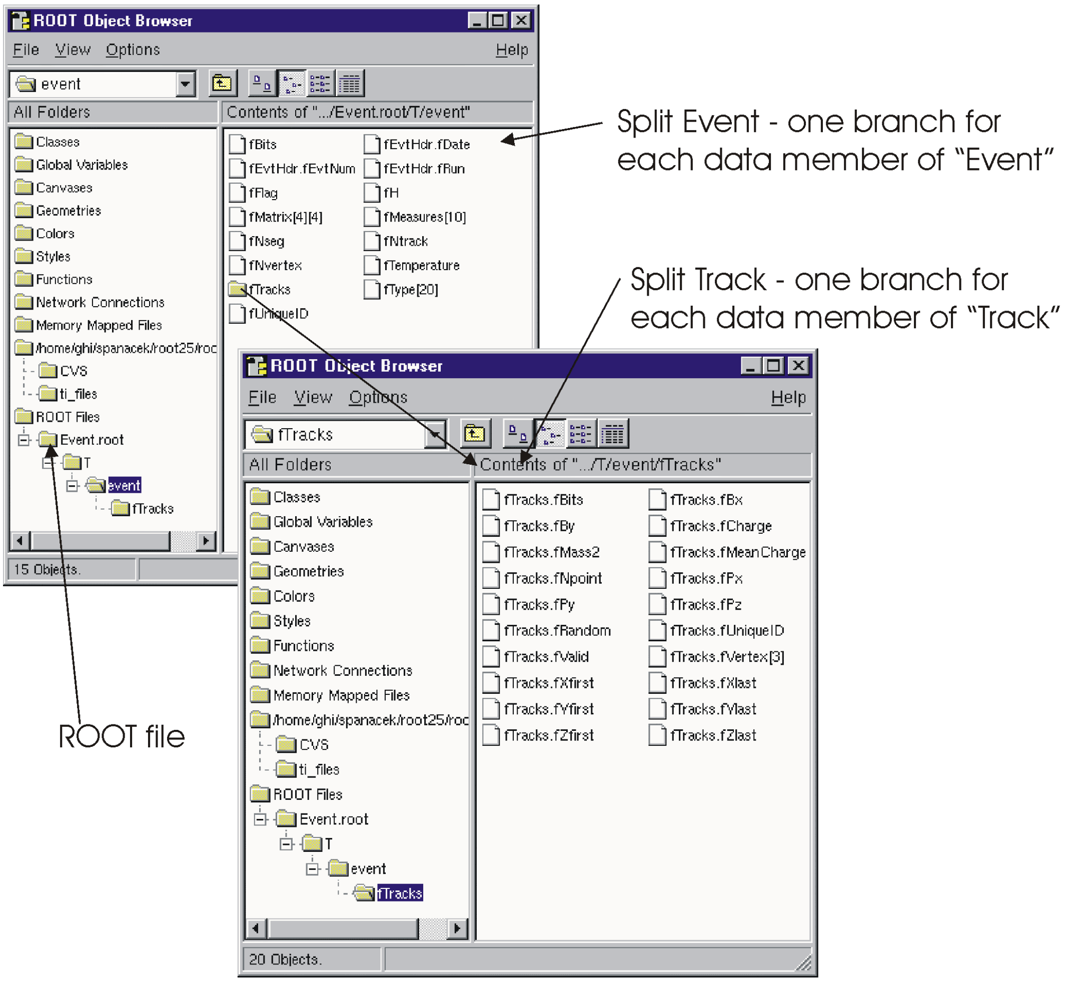
We notice that only one branch is visible (event). The individual data members of the `Event` object are no longer visible in the browser. They are contained in the event object on the event branch, because we specified no splitting.

Split Level = 1:

Setting the split level to 1 will create a branch for each data member in the Event object. We can see this by browsing the resulting files.

First we execute `Event` and set the split level to 1 and start the browser to examine the split tree:

```
> Event 400 1 1 1
> root
root [] TFile f("Event.root")
root [] TBrowser browser
```



stress - Test and Benchmark

The executable `stress` is created by compiling `stress.cxx`. It completes sixteen tests covering the following capabilities of the ROOT framework.

1. Functions, Random Numbers, Histogram Fits
2. Size & compression factor of a ROOT file
3. Purge, Reuse of gaps in `TFile`
4. 2D Histograms, Functions, 2D Fits
5. Graphics & PostScript
6. Subdirectories in a ROOT file
7. `TNtuple`, Selections, `TCut`, `TCutG`, `TEventList`
8. Split and Compression modes for Trees
9. Analyze `Event.root` file of stress 8
10. Create 10 files starting from `Event.root`
11. Test chains of Trees using the 10 files
12. Compare histograms of test 9 and 11
13. Merging files of a chain
14. Check correct rebuilt of `Event.root` in test 13
15. Divert Tree branches to separate files
16. CINT test (3 nested loops) with `LHCb` trigger

The program `stress` takes one argument, the number of events to process. The default is 1000 events. Be aware that executing stress with 1000 events will create several files consuming about 100 MB of disk space; running stress with 30 events will consume about 20 MB. The disk space is released once `stress` is done.

There are two ways to run stress:

From the system prompt or from the ROOT prompt using the interpreter. Start ROOT with the batch mode option (-b) to suppress the graphic output.

```
> cd $ROOTSYS/test
> stress              // default 1000 events
> stress 30           // test with 30 events
```

```
> root -b
root [] .x stress.cxx       // default 1000 events
root [] .x stress.cxx (30)  // test with 30 events
```

The output of stress includes a pass/fail conclusion for each test, the total number of bytes read and written, and the elapsed real and CPU time. It also calculates a performance index for your machine relative to a reference machine a DELL Inspiron 7500 (Pentium III 600 MHz) with 256 MB of memory and 18 GBytes IDE disk in ROOTMARKS. Higher ROOTMARKS means better performance. The reference machine has 200 ROOTMARKS, so the sample run below with 53.7 ROOTMARKS is about four times slower than the reference machine.

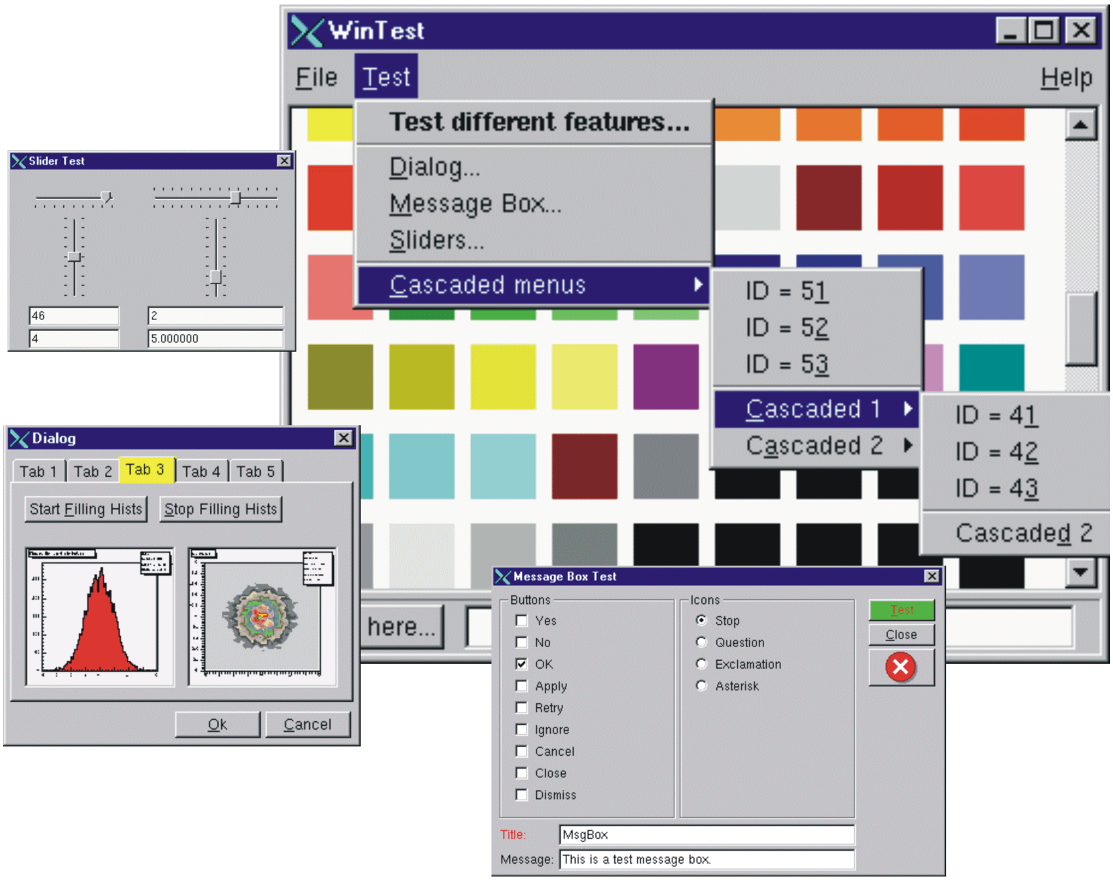
Here is a sample run:

```
% root –b
root [] .x stress.cxx (30)

Test  1 : Functions, Random Numbers, Histogram Fits............. OK
Test  2 : Check size & compression factor of a Root file........ OK
Test  3 : Purge, Reuse of gaps in TFile......................... OK
Test  4 : Test of 2-d histograms, functions, 2-d fits........... OK
Test  5 : Test graphics & PostScript ............................OK
Test  6 : Test subdirectories in a Root file.................... OK
Test  7 : TNtuple, selections, TCut, TCutG, TEventList.......... OK
Test  8 : Trees split and compression modes..................... OK
Test  9 : Analyze Event.root file of stress 8................... OK
Test 10 : Create 10 files starting from Event.root.............. OK
Test 11 : Test chains of Trees using the 10 files............... OK
Test 12 : Compare histograms of test 9 and 11................... OK
Test 13 : Test merging files of a chain......................... OK
Test 14 : Check correct rebuilt of Event.root in test 13........ OK
Test 15 : Divert Tree branches to separate files................ OK
Test 16 : CINT test (3 nested loops) with LHCb trigger.......... OK
******************************************************************
*  IRIX64 fnpat1 6.5 01221553 IP27
******************************************************************
stress    : Total I/O =   75.3 Mbytes, I =   59.2, O =  16.1
stress    : Compr I/O =   75.7 Mbytes, I =   60.0, O =  15.7
stress    : Real Time = 307.61 seconds Cpu Time = 292.82 seconds
******************************************************************
*  ROOTMARKS =  53.7   *  Root2.25/00   20000710/1022
```

guitest – A Graphical User Interface

The `guitest` example, created by compiling `guitest.cxx`, tests and illustrates the use of the native GUI widgets such as cascading menus, dialog boxes, sliders and tab panels. It is a very useful example to study when designing a GUI. Below are some examples of the output of `guitest`, to run it type `guitest` at the system prompt in the `$ROOTSYS/test` directory.

We have included an entire chapter on this subject where we explore `guitest` in detail and use it to explain how to build our own ROOT application with a GUI (see Chapter Writing a Graphical User Interface).



15 Example Analysis

This chapter is an example of a typical physics analysis. Large data files are chained together and analyzed using the `TSelector` class.

Explanation

This script uses four large data sets from the H1 collaboration at DESY Hamburg. One can access these data sets (277 Mbytes) from the ROOT web site at: ftp://root.cern.ch/root/h1analysis/

The physics plots generated by this example cannot be produced using smaller data sets.

There are several ways to analyze data stored in a ROOT Tree

- Using `TTree::Draw`:
  This is very convenient and efficient for small tasks. A `TTree::Draw` call produces one histogram at the time. The histogram is automatically generated. The selection expression may be specified in the command line.
- Using the `TTreeViewer`:
  This is a graphical interface to `TTree::Draw` with the same functionality.
- Using the code generated by `TTree::MakeClass`:
  In this case, the user creates an instance of the analysis class. He has the control over the event loop and he can generate an unlimited number of histograms.
- Using the code generated by `TTree::MakeSelector`:
  Like for the code generated by `TTree::MakeClass`, the user can do complex analysis. However, he cannot control the event loop. The event loop is controlled by `TTree::Process` called by the user. This solution is illustrated by the code below. The advantage of this method is that it can be run in a parallel environment using PROOF (the Parallel Root Facility).

A chain of four files (originally converted from PAW ntuples) is used to illustrate the various ways to loop on ROOT data sets. Each contains a ROOT Tree named "`h42`". The class definition in `h1analysis.h` has been generated automatically by the ROOT utility `TTree::MakeSelector` using one of the files with the following statement:

```
h42->MakeSelector("h1analysis");
```

This produces two files: `h1analysis.h` and `h1analysis.C`. A skeleton of `h1analysis.C` file is made for you to customize. The `h1analysis` class is derived from the ROOT class `TSelector`. The following members functions of `h1analyhsis` (i.e. `TSelector`) are called by the `TTree::Process` method.

- `Begin`: This function is called every time a loop over the tree starts. This is a convenient place to create your histograms.
- `Notify()`: This function is called at the first entry of a new tree in a chain.
- `ProcessCut`: This function is called at the beginning of each entry to return a flag true if the entry must be analyzed.
- `ProcessFill`: This function is called in the entry loop for all entries accepted by Select.
- `Terminate`: This function is called at the end of a loop on a `TTree`. This is a convenient place to draw and fit your histograms.

To use this program, try the following session.

First, turn the timer on to show the real and CPU time per command.

```
root[] gROOT->Time();
```

Step A: create a `TChain` with the four H1 data files. The chain can be created by executed this short script `h1chain.C` below. `$H1` is a system symbol pointing to the H1 data directory.

```
{
  TChain chain("h42");
  chain.Add("$H1/dstarmb.root");
      //21330730 bytes, 21920 events
  chain.Add("$H1/dstarp1a.root");
      //71464503 bytes, 73243 events
  chain.Add("$H1/dstarp1b.root");
      //83827959 bytes, 85597 events
  chain.Add("$H1/dstarp2.root");
      //100675234 bytes, 103053 events
}
```

Run the above script from the command line:

```
root[] .x h1chain.C
```

Step B: Now we have a directory containing the four data files. Since a `TChain` is a descendent of `TTree` we can call `TChain::Process` to loop on all events in the chain. The parameter to the `TChain::Process` method is the name of the file containing the created `TSelector` class (`h1analysis.C`).

```
root[] chain.Process("h1analysis.C")
```

Step C: Same as step A, but in addition fill the event list with selected entries. The event list is saved to a file "`elist.root`" by the

TSelector::Terminate method. To see the list of selected events, you can do `elist->Print("all")`. The selection function has selected 7525 events out of the 283813 events in the chain of files. (2.65 per cent)

```
root[] chain.Process("h1analysis.C","fillList")
```

Step D: Process only entries in the event list. The event list is read from the file in `elist.root` generated by step C.

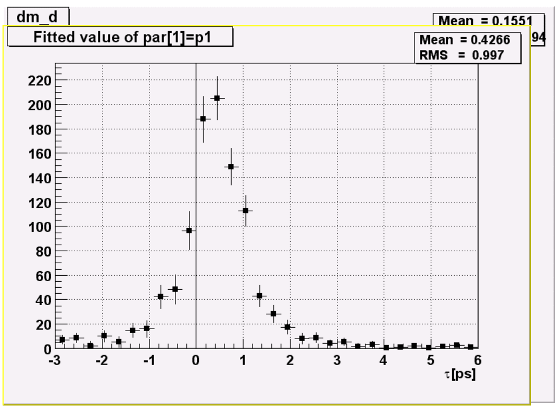
```
root[] chain.Process("h1analysis.C","useList")
```

Step E: The above steps have been executed with the interpreter. You can repeat the steps 2, 3, and 4 using ACLiC by replacing "`h1analysis.C`" by "`h1analysis.C+`" or "`h1analysis.C++`".

Step F: If you want to see the differences between the interpreter speed and ACLiC speed start a new session, create the chain as in step 1, then execute

```
root[] chain.Process("h1analysis.C+","useList")
```

The commands executed with the four different methods B, C, D and E produce two canvases shown below:



Script

This is the `h1analsysis.C` file that was generated by `TTree::MakeSelector` and then modified to perform the analysis.

```
#include "h1analysis.h"
#include "TH2.h"
#include "TF1.h"
#include "TStyle.h"
#include "TCanvas.h"
#include "TLine.h"
#include "TEventList.h"

const Double_t dxbin = (0.17-0.13)/40;   // Bin-width
const Double_t sigma = 0.0012;
TEventList *elist = 0;
Bool_t useList, fillList;
TH1F *hdmd;
TH2F *h2;

//___________________________________________________________
Double_t fdm5(Double_t *xx, Double_t *par)
{
   Double_t x = xx[0];
   if (x <= 0.13957) return 0;
   Double_t xp3 = (x-par[3])*(x-par[3]);
   Double_t res =
      dxbin*(par[0]*TMath::Power(x-0.13957, par[1])
      + par[2] / 2.5066 / par[4]*TMath::Exp(
      xp3/2/par[4]/par[4]));
   return res;
}

//___________________________________________________________
Double_t fdm2(Double_t *xx, Double_t *par)
{
   Double_t x = xx[0];
   if (x <= 0.13957) return 0;
   Double_t xp3 = (x-0.1454)*(x-0.1454);
    Double_t res = dxbin*(par[0]*TMath::Power(x-0.13957, 0.25)
      + par[1] / 2.5066/sigma*TMath::Exp(
      xp3/2/sigma/sigma));
   return res;
}

//___________________________________________________________
void h1analysis::Begin(TTree *tree)
{
// function called before starting the event loop
//  -it performs some cleanup
//  -it creates histograms
//  -it sets some initialization for the event list

   //initialize the Tree branch addresses
   Init(tree);

   //print the option specified in the Process function.
   TString option = GetOption();
   printf("Starting h1analysis with process option:
```

```
      %sn",option.Data());

   //Some cleanup in case this function had
   //already been executed.
   //Delete any previously generated histograms or
   //functions
   gDirectory->Delete("hdmd");
   gDirectory->Delete("h2*");
   delete gROOT->GetFunction("f5");
   delete gROOT->GetFunction("f2");

   //create histograms
   hdmd = new TH1F("hdmd","dm_d",40,0.13,0.17);
   h2   = new TH2F
      ("h2","ptD0 vs dm_d",30,0.135,0.165,30,-3,6);

   //process cases with event list
   fillList = kFALSE;
   useList  = kFALSE;
   fChain->SetEventList(0);
   delete gDirectory->GetList()->FindObject("elist");

   // case when one creates/fills the event list
   if (option.Contains("fillList")) {
      fillList = kTRUE;
      elist = new TEventList
            ("elist","selection from Cut",5000);
   }
   // case when one uses the event list generated
   // in a previous call
   if (option.Contains("useList")) {
      useList  = kTRUE;
      TFile f("elist.root");
      elist = (TEventList*)f.Get("elist");
      if (elist) elist->SetDirectory(0);
      //otherwise the file destructor will delete elist
      fChain->SetEventList(elist);
   }
}

//______________________________________________________________
Bool_t h1analysis::ProcessCut(Int_t entry)
{
// Selection function to select D* and D0.

   //in case one event list is given in input,
   //the selection has already been done.
   if (useList) return kTRUE;

   // Read only the necessary branches to select entries.
   // return as soon as a bad entry is detected
   b_md0_d->GetEntry(entry);
   if (TMath::Abs(md0_d-1.8646) >= 0.04) return kFALSE;
   b_ptds_d->GetEntry(entry);
   if (ptds_d <= 2.5) return kFALSE;
   b_etads_d->GetEntry(entry);
   if (TMath::Abs(etads_d) >= 1.5) return kFALSE;
   b_ik->GetEntry(entry);  ik--;
   //original ik used f77 convention starting at 1
   b_ipi->GetEntry(entry); ipi--;
```

```
   b_ntracks->GetEntry(entry);
   b_nhitrp->GetEntry(entry);
   if (nhitrp[ik]*nhitrp[ipi] <= 1) return kFALSE;
   b_rend->GetEntry(entry);
   b_rstart->GetEntry(entry);
   if (rend[ik] -rstart[ik]  <= 22) return kFALSE;
   if (rend[ipi]-rstart[ipi] <= 22) return kFALSE;
   b_nlhk->GetEntry(entry);
   if (nlhk[ik] <= 0.1)    return kFALSE;
   b_nlhpi->GetEntry(entry);
   if (nlhpi[ipi] <= 0.1)  return kFALSE;
   b_ipis->GetEntry(entry);
   ipis--;
   if (nlhpi[ipis] <= 0.1) return kFALSE;
   b_njets->GetEntry(entry);
   if (njets < 1)          return kFALSE;

   // if option fillList, fill the event list

   if (fillList) elist->Enter
      (fChain->GetChainEntryNumber(entry));
   return kTRUE;
}


//______________________________________________________________
void h1analysis::ProcessFill(Int_t entry)
{
// Function called for selected entries only

   // read branches not processed in ProcessCut

   b_dm_d->GetEntry(entry);
        //read branch holding dm_d
   b_rpd0_t->GetEntry(entry);
       //read branch holding rpd0_t
   b_ptd0_d->GetEntry(entry);
       //read branch holding ptd0_d

   //fill some histograms

   hdmd->Fill(dm_d);
   h2->Fill(dm_d,rpd0_t/0.029979*1.8646/ptd0_d);
}

//______________________________________________________________
void h1analysis::Terminate()
{
// Function called at the end of the event loop

   //create the canvas for the h1analysis fit

   gStyle->SetOptFit();
   TCanvas *c1 = new TCanvas
      ("c1","h1analysis analysis",10,10,800,600);
   c1->SetBottomMargin(0.15);
   hdmd->GetXaxis()->SetTitle
      ("m_{K#pi#pi} - m_{K#pi}[GeV/c^{2}]");
   hdmd->GetXaxis()->SetTitleOffset(1.4);

   //fit histogram hdmd with function f5 using
```

```
   //the loglikelihood option

   TF1 *f5 = new TF1("f5",fdm5,0.139,0.17,5);
   f5->SetParameters(1000000, .25, 2000, .1454, .001);
   hdmd->Fit("f5","lr");

   //create the canvas for tau d0

   gStyle->SetOptFit(0);
   gStyle->SetOptStat(1100);
   TCanvas *c2 = new TCanvas("c2","tauD0",100,100,800,600);
   c2->SetGrid();
   c2->SetBottomMargin(0.15);

   // Project slices of 2-d histogram h2 along X ,
   // then fit each slice with function f2 and make a
   // histogram for each fit parameter.
   // Note that the generated histograms are added
   // to the list of objects in the current directory.

   TF1 *f2 = new TF1("f2",fdm2,0.139,0.17,2);
   f2->SetParameters(10000, 10);
   h2->FitSlicesX(f2,0,0,1,"qln");
   TH1D *h2_1 = (TH1D*)gDirectory->Get("h2_1");
   h2_1->GetXaxis()->SetTitle("#tau[ps]");
   h2_1->SetMarkerStyle(21);
   h2_1->Draw();
   c2->Update();
   TLine *line = new TLine(0,0,0,c2->GetUymax());
   line->Draw();

   // save the event list to a Root file if one was
   // produced
   if (fillList) {
      TFile efile("elist.root","recreate");
      elist->Write();
   }
}
```

16 Networking

In this chapter, you will learn how to send data over the network using the ROOT socket classes.

Setting up a Connection

On the server side, we create a `TServerSocket` to wait for a connection request over the network. If the request is accepted, it returns a full-duplex socket. Once the connection is accepted, we can communicate to the client that we are ready to go by sending the string "go", and we can close the server socket.

```
{ // server
  TServerSocket *ss = new TServerSocket(9090, kTRUE);
  TSocket *socket = ss->Accept();
  socket->Send("go");
  ss->Close();
}
```

On the client side, we create a socket and ask the socket to receive input.

```
{ // client
  TSocket *socket = new TSocket("localhost", 9090);
  Char str[32];
  Socket->Recv(str,32);
}
```

Sending Objects over the Network

We have just established a connection and you just saw how to send and receive a string with the example "go". Now let's send a histogram.

To send an object (in our case on the client side) it has to derive from `TObject` because it uses the `Streamers` to fill a buffer that is then sent over the connection. On the receiving side, the `Streamers` are used to read the object from the message sent via the socket. For network communication, we have a specialized `TBuffer`, a descendant of `TBuffer` called `TMessage`. In the following example, we create a `TMessage` with the intention to store an object, hence the constant `kMESS_OBJECT` in the constructor. We create and fill the histogram and write it into the message. Then we call `TSocket::Send` to send the message with the histogram.

```
…
// create an object to be sent
TH1F *hpx = new TH1F("hpx","px distribution",100,-4,4);
hpx->FillRandom("gaus",1000);
// create a TMessage to send the object
TMessage message(kMESS_OBJECT);
// write the histogram into the message buffer
message.WriteObject(hpx);
// send the message
socket->Send(message);
…
```

On the receiving end (in our case the server side), we write a while loop to wait and receive a message with a histogram. Once we have a message, we call `TMessage::ReadObject`, which returns a pointer to `TObject`. We have to cast it to a `TH1` pointer, and now we have a histogram. At the end of the loop, the message is deleted, and another one is created at the beginning.

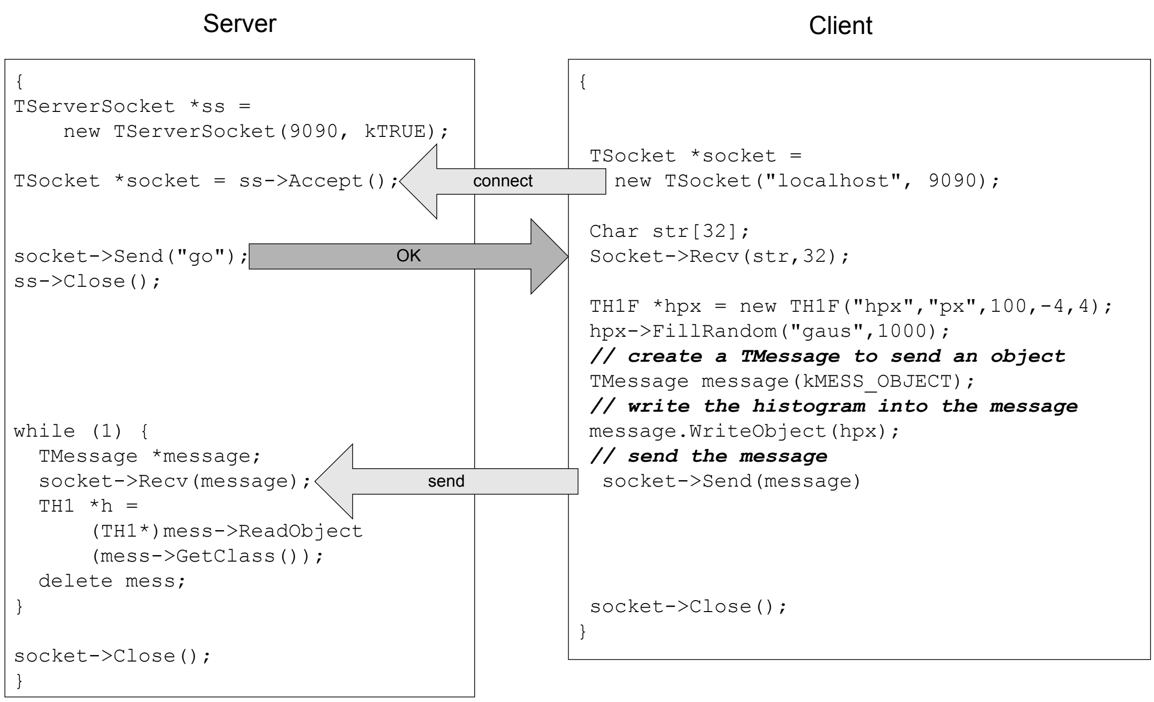
```
…
while (1) {
  TMessage *message;
  socket->Recv(message);
  TH1 *h = (TH1*)message->ReadObject(message->GetClass());
  delete message;
}
…
```

Closing the Connection

Once we are done sending objects, we close the connection by closing the sockets at both ends.

```
   …
   Socket->Close();
}
```

This diagram summarizes the steps we just covered:



A Server with Multiple Sockets

Chances are that your server has to be able to receive data from multiple clients. The class we need for this is `TMonitor`. It lets you add sockets and the `TMonitor::Select` method returns the socket with data waiting. Sockets can be added, removed, or enabled and disabled.

Here is an example of a server that has a `TMonitor` to manage multiple sockets:

```
{
   TServerSocket *ss = new  TServerSocket (9090, kTRUE);

   // Accept a connection and return a full-duplex
   // communication socket.
   TSocket *s0 = ss->Accept();
   TSocket *s1 = ss->Accept();

   // tell the clients to start
   s0->Send("go 0");
   s1->Send("go 1");

   // Close the server socket (unless we will use it
   // later to wait for another connection).
   ss->Close();

   TMonitor *mon = new TMonitor;

   mon->Add(s0);
   mon->Add(s1);

   while (1) {
      TMessage *mess;
      TSocket  *s;
      s = mon->Select();
      s->Recv(mess);
…
}
```

The full code for the example above is in `$ROOTSYS/tutorials/hserver.cxx` and `$ROOTSYS/tutorials/hclient.cxx`.

17 Writing a Graphical User Interface

The ROOT GUI classes support an extensive and rich set of widgets. The widgets classes depend only on the `X11` and `Xpm` libraries, eliminating the need for any other GUI engine such as Motif or QT, and they have the Windows look and feel. They are based on Hector Peraza's Xclass'95 widget library.

Although powerful and quite feature rich, we are missing extensive documentation. This will come eventually but for the time being you will have to "program by example". We start with a short tutorial followed by few non-trivial examples that will show how to use the different widget classes.

The New ROOT GUI Classes

Features of the new GUI classes in a nutshell:

- Originally based on Xclass'95 widget library (under a Lesser GNU Public License)
    - A rich and complete set of widgets
    - Uses only X11 and Xpm (no Motif, Xaw, Xt, etc.)
    - Small (12000 lines of C++)
    - Win'95 look and feel
- All X11 calls abstracted using in the "abstract" ROOT TGXW class
- Rewritten to use internally the ROOT container classes
- Completely scriptable via the C++ interpreter (fast prototyping)
- Full class documentation is generated automatically (as for all ROOT classes)

XClass'95

Here are some highlights of the XClass'95. Hector Peraza is the original author of the XClass'95 class library.

The Xclass'95 comes with a complete set of widgets. These include:

- Simple widgets, as labels and icons
- Push buttons, either with text or pix maps
- Check buttons
- Radio buttons
- Menu bars and popup menus

- Scroll bars
- Scrollable canvas
- List boxes
- Combo boxes
- Group frames
- Text entry widgets
- Tab widgets
- General-purpose composite widgets, for building toolbars and status bars
- Dialog classes and top-level window classes

The widgets are shown in frames:

frame, composite frame, main frame, transient frame, group frame

And arranged by layout managers**:**

horizontal layout, vertical layout, row layout, list layout, tile layout, matrix layout, ...

Using a combination of layout hints:

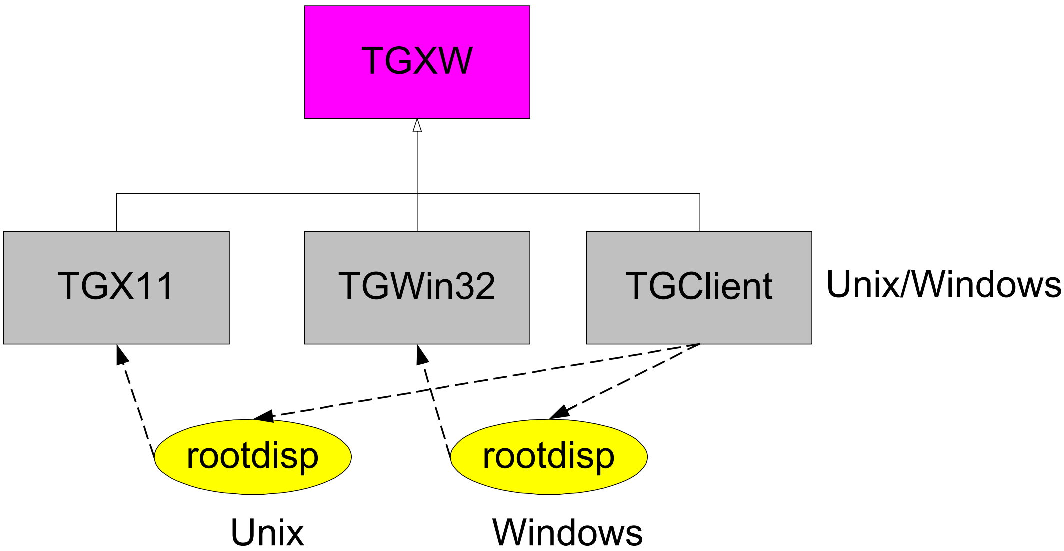
left, center x, right, top, center y, bottom, expand x, expand y and fixed offsets

Event handling by messaging (as opposed to callbacks): in response to actions widgets send messages (`SendMessage()`) to associated frames (`ProcessMessage()`)

ROOT Integration

Replace all calls to X11 by calls to the ROOT abstract graphics base class `TGXW`. Currently, implementations of `TGXW` exist X11 (`TGX11`) and Win32 (`TGWin32`). Thanks to this single graphics interface, porting ROOT to a new platform (BeOS, Rhapsody, etc.) requires only the implementation of `TGXW` (and `TSystem`).

Abstract Graphics Base Class TGXW



Concrete implementations of `TGXW` are `TGX11`, for X Windows, `TGWin32` for Win95/NT. The `TGXClient` implementation provides a network interface allowing for remote display via the `rootdisp` servers.

NOTE: the ROOT GUI classes are for the time being only supported on **Unix/X11** systems. Work on a Win32 port is in progress and coming shortly

---

Further changes:

- Changed internals to use ROOT container classes, notably hash tables for fast lookup of frame and picture objects
- Added `TObject` inheritance to the few base classes to get access to the extended ROOT RTTI (type information and object inspection) and documentation system
- Conversion to the ROOT naming conventions to provide a homogeneous and consistent environment for the user

A Simple Example

The code that uses the GUI classes is written in bold font.

```
#include <TROOT.h>
#include <TApplication.h>
#include <TGClient.h>
extern void InitGui();
VoidFuncPtr_t initfuncs[] = { InitGui, 0 };
TROOT root("GUI", "GUI test environement", initfuncs);
int main(int argc, char **argv)
{
    TApplication theApp("App", &argc, argv);
    MyMainFrame mainWin(gClient->GetRoot(), 200, 220);
    theApp.Run();
    return 0;
}
```

MyMainFrame

```
#include <TGClient.h>
#include <TGButton.h>
class MyMainFrame : public TGMainFrame {
private:
    TGTextButton    *fButton1, *fButton2;
    TGPictureButton *fPicBut;
    TGCheckButton   *fChkBut;
    TGRadioButton   *fRBut1, *fRBut2;
    TGLayoutHints   *fLayout;
public:
    MyMainFrame(const TGWindow *p, UInt_t w, UInt_t h);
    ~MyMainFrame();
    Bool_t ProcessMessage(Long_t msg, Long_t parm1, Long_t
parm2);
};
```

Laying out the Frame

```
MyMainFrame::MyMainFrame(const TGWindow *p, UInt_t w,
UInt_t h): TGMainFrame(p, w, h)
{
 // Create a main frame with a number of different buttons.

    fButton1 = new TGTextButton(this, "&Version", 1);
    fButton1->SetCommand("printf
          (\"This is ROOT version %s\\n\",
      gROOT->GetVersion());");
    fButton2 = new TGTextButton(this, "&Exit", 2);
    fButton2->SetCommand(".q" );
    fPicBut = new TGPictureButton(
            this, gClient->GetPicture("world.xpm"), 3);
    fPicBut->SetCommand("printf(\"hello world!\\n\");");
    fChkBut = new TGCheckButton(this, "Check Button", 4);
    fRBut1  = new TGRadioButton(this, "Radio Button 1", 5);
    fRBut2  = new TGRadioButton(this, "Radio Button 2", 6);
    fLayout = new TGLayoutHints
      (kLHintsCenterX | kLHintsCenterY);
    AddFrame(fButton1, fLayout);
    AddFrame(fPicBut, fLayout);
    AddFrame(fButton2, fLayout);
    AddFrame(fChkBut, fLayout);
    AddFrame(fRBut1, fLayout);
    AddFrame(fRBut2, fLayout);
    MapSubwindows();
    Layout();
    SetWindowName("Button Example");
    SetIconName("Button Example");
    MapWindow();
}
```

Adding Actions

```
Bool_t MyMainFrame::ProcessMessage(Long_t msg, Long_t
parm1, Long_t)
{
// Process events generated by the buttons in the frame.
 switch (GET_MSG(msg)) {
  case kC_COMMAND:
   switch (GET_SUBMSG(msg)) {
     case kCM_BUTTON:
        printf("text button id %ld pressed\n", parm1);
        break;
     case kCM_CHECKBUTTON:
        printf("check button id %ld pressed\n", parm1);
        break;
     case kCM_RADIOBUTTON:
       if (parm1 == 5)
         fRBut2->SetState(kButtonUp);
       if (parm1 == 6)
         fRBut1->SetState(kButtonUp);
       printf("radio button id %ld pressed\n", parm1);
       break;
     default:
       break;
   }
   default:
     break;
  }
  return kTRUE;
}
```

The Result

The Widgets in Detail

In this section we look at an example of using the widgets. The complete source code is in `$ROOTSYS/test/guitest.C`. Build the test directory with the appropriate makefile, and you will be able to run guitest. Here we present snippets of the code and the graphical output.

First the main program, which reveals that the functionality is in TestMainFrame.

```
TROOT root("GUI", "GUI test environement");

int main(int argc, char **argv)
{
   TApplication theApp("App", &argc, argv);
   if (gROOT->IsBatch()) {
      fprintf(stderr,
         "%s: cannot run in batch mode\n", argv[0]);
      return 1;
   }
   TestMainFrame mainWindow(gClient->GetRoot(), 400, 220);
   theApp.Run();
   return 0;
}
```

TestMainFrame has two subframes (TGCompositFrame), a canvas, a text entry field, a button, a menu bar, several popup menus, and layout hints. It has a public constructor, destructor and a ProcessMessage method to carry out the actions.

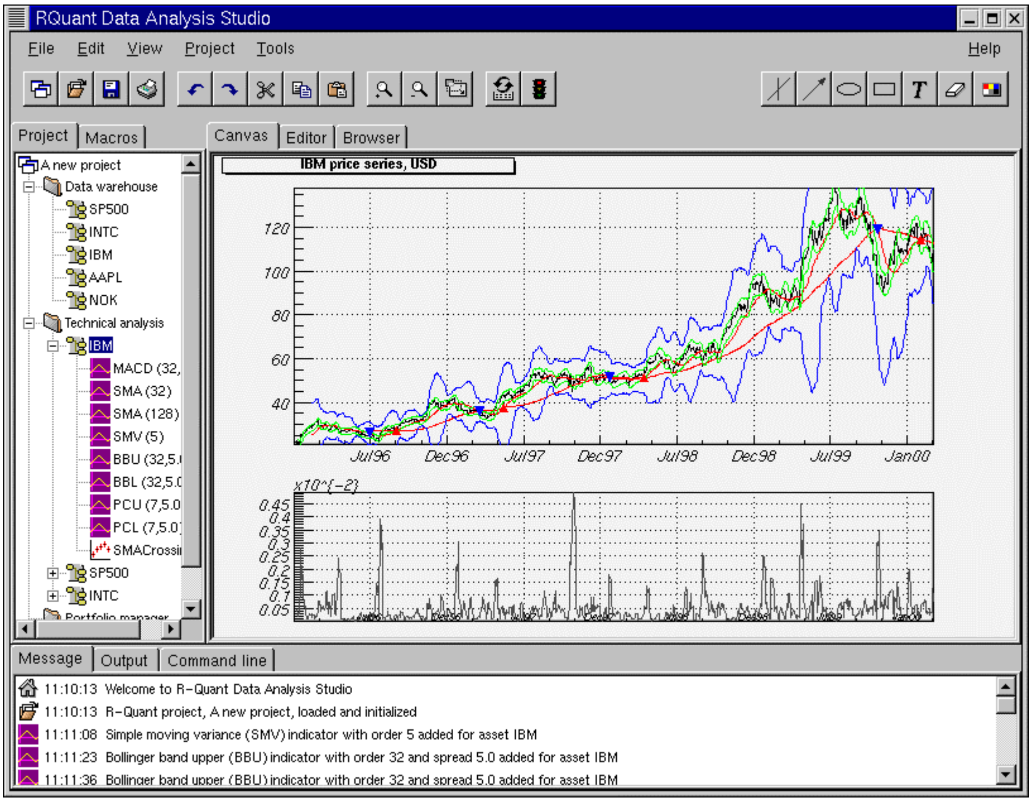
```
class TestMainFrame : public TGMainFrame {

private:
   TGCompositeFrame   *fStatusFrame;
   TGCanvas           *fCanvasWindow;
   TGCompositeFrame   *fContainer;
   TGTextEntry        *fTestText;
   TGButton           *fTestButton;

   TGMenuBar          *fMenuBar;
   TGPopupMenu        *fMenuFile, *fMenuTest, *fMenuHelp;
   TGPopupMenu        *fCascadeMenu,
                      *fCascade1Menu, *fCascade2Menu;
   TGLayoutHints      *fMenuBarLayout, *fMenuBarItemLayout,
                      *fMenuBarHelpLayout;

public:
   TestMainFrame(const TGWindow *p, UInt_t w, UInt_t h);
   virtual ~TestMainFrame();

   virtual void CloseWindow();
   virtual Bool_t ProcessMessage(Long_t msg, Long_t parm1,
Long_t);
};
```

Example: Widgets and the Interpreter

The script $ROOTSYS/tutorials/dialogs.C shows how the widgets can be used from the **interpreter**.

RQuant Example

This is an example of extensive use of the ROOT GUI classes. I include only a picture here, for the curious the full documentation or RQuant can be found at: http://svedaq.tsl.uu.se/~anton/rquant.htm



References

http://home.cern.ch/~chytrace/xclasstut.html
A basic introduction and mini tutorial on the `Xclass` by Hector Peraza's

ac.be/html-test/xclass.html
The original Xclass'95 widget library documentation and source by Hector Peraza's.

http://svedaq.tsl.uu.se/~anton/rquant.htm
An Example of an elaborate ROOT GUI application.

18 Automatic HTML Documentation

The class descriptions on the ROOT website have been generated automatically by ROOT itself with the `THtml` class. With it, you can automatically generate (and update) a reference guide for your ROOT classes. Please read this class description and the paragraph on Coding Conventions.

The following illustrates how to generate an html class description using the `MakeClass` method. In this example class name is `TBRIK`.

```
root[] gHtml->MakeClass("TBRIK")
```

How to generate html code for all classes, including an index.

```
root[] gHtml->MakeAll();
```

This example also shows how to convert a script to html, including the generation of a "gif" file produced by the script. First execute the script.

```
root[] .x htmlex.C
```

Invoke the `TSystem` class to execute a shell script. Here we call the "`xpick`" program to capture the graphics window into a `gif` file.

```
root[] gSystem->Exec("xpick html/gif/shapes.gif")
```

Convert this script into html.

```
root[] gHtml->Convert("htmlex.C","Auto HTML document
generation")
```

For more details see the documentation of the class `THtml`.

19 PROOF: Parallel Processing

Building on the experience gained from the implementation and operation of the PIAF system we have developed the parallel ROOT facility, PROOF. The main problems with PIAF were because its proper parallel operation depended on a cluster of homogenous equally performing and equally loaded machines. Due to PIAF's simplistic portioning of a job in N equal parts, where N is the number of processors, the overall performance was governed by the slowest node. The running of a PIAF cluster was an expensive operation since it required a cluster dedicated solely to PIAF. The cluster could not be used for other types of jobs without destroying the PIAF performance.

In the implementation of PROOF, we made the slave servers the active components that ask the master server for new work whenever they are ready. In the scheme the parallel processing performance is a function of the duration of each small job, packet, and the networking bandwidth and latency. Since the bandwidth and latency of a networked cluster are fixed the main tunable parameter in this scheme is the packet size. If the packet size is too small the parallelism will be destroyed by the communication overhead caused by the many packets sent over the network between the master and the slave servers. If the packet size is too large, the effect of the difference in performance of each node is not evened out sufficiently.

Another very important factor is the location of the data. In most cases, we want to analyze a large number of data files, which are distributed over the different nodes of the cluster. To group these files together we use a chain. A chain provides a single logical view of the many physical files. To optimize performance by preventing huge amounts of data being transferred over the network via NFS or any other means when analyzing a chain, we make sure that each slave server is assigned a packet, which is local to the node. Only when a slave has processed all its local data will it get packets assigned that cause remote access. A packet is a simple data structure of two numbers: begin event and number of events. The master server generates a packet when asked for by a slave server, taking into account t the time it took to process the previous packet and which files in the chain are local to the lave server. The master keeps a list of all generated packets per slave, so in case a slave dies during processing, all its packets can be reprocessed by the left over slaves.

20 Threads

A thread is an independent flow of control that operates within the same address space as other independent flows of controls within a process. In most UNIX systems, thread and process characteristics are grouped into a single entity called a process. Sometimes, threads are called "lightweight processes".

Note:This introduction is adapted from the AIX 4.3 Programmer's Manual.

Threads and Processes

In traditional single-threaded process systems, a process has a set of properties. In multi-threaded systems, these properties are divided between processes and threads.

Process Properties

A process in a multi-threaded system is the changeable entity. It must be considered as an execution frame. It has all traditional process attributes, such as:

- Process ID, process group ID, user ID, and group ID
- Environment
- Working directory

A process also provides a common address space and common system resources:

- File descriptors
- Signal actions
- Shared libraries
- Inter-process communication tools (such as message queues, pipes, semaphores, or shared memory)

Thread Properties

A thread is the schedulable entity. It has only those properties that are required to ensure its independent flow of control. These include the following properties:

- Stack
- Scheduling properties (such as policy or priority)
- Set of pending and blocked signals
- Some thread-specific data (TSD)

An example of thread-specific data is the error indicator, `errno`. In multi-threaded systems, `errno` is no longer a global variable, but usually a subroutine returning a thread-specific `errno` value. Some other systems may provide other implementations of `errno`.

With respect to ROOT, a thread specific data is for example the `gPad` pointer, which is treated in a different way, whether it is accessed from any thread or the main thread.

Threads within a process must not be considered as a group of processes (even though in Linux each thread receives an own process id, so that it can be scheduled by the kernel scheduler). All threads share the same address space. This means that two pointers having the same value in two threads refer to the same data. Also, if any thread changes one of the shared system resources, all threads within the process are affected. For example, if a thread closes a file, the file is closed for all threads.

The Initial Thread

When a process is created, one thread is automatically created. This thread is called the initial thread or the main thread. The initial thread executes the main routine in multi-threaded programs.

Note: At the end of this chapter is a glossary of thread specific terms

Implementation of Threads in ROOT

The `TThread` class has been developed to provide a platform independent interface to threads for ROOT.

Installation

For the time being, it is still necessary to compile a threaded version of ROOT to enable some very special treatments of the canvas operations. We hope that this will become the default later.

To compile ROOT, just do (for example on a debian Linux):

```
./configure linuxdeb2 --with-thread=/usr/lib/libpthread.so
gmake depend
gmake
```

This configures and builds ROOT using `/usr/lib/libpthread.so` as the `Pthread` library, and defines R__THREAD. This enables the thread specific treatment of `gPad`, and creates `$ROOTSYS/lib/libThread.so`.

Note: The parameter `linuxdeb2` has to be replaced with the appropriate ROOT keyword for your platform.

Classes

`TThread`

This class implements threads. The platform dependent implementation is in the `TThreadImp` class and its descendant classes (e.g. `TPosixThread`).

`TMutex`

This class implements mutex locks. A mutex is a mutually exclusive lock. The platform dependent implementation is in the `TMutexImp` class and its descendant classes (e.g. `TPosixMutex`)

`TCondition`

This class implements a condition variable. Use a condition variable to signal threads. The platform dependent implementation is in the `TConditionImp` class and its descendant classes (e.g. `TPosixCondition`).

`TSemaphore`

This class implements a counting semaphore. Use a semaphore to synchronize threads. The platform dependent implementation is in the `TMutexImp` and `TConditionImp` classes.

TThread for Pedestrians

To run a thread in ROOT, follow these steps:

Initialization:

Add these lines to your `rootlogon.C`:

```
{
   …
   // The next line may be unnecessary on some platforms
   gSystem->Load("/usr/lib/libpthread.so");
   gSystem->Load("$ROOTSYS/lib/libThread.so");
   …
}
```

This loads the library with the `TThread` class and the `pthread` specific implementation file for Posix threads.

Coding:

Define a function (e.g. `void* UserFun(void* UserArgs)`) that should run as a thread. The code for the examples is at the web site of the authors (Jörn Adamczewski, Marc Hemberger). After downloading the code from this site, you can follow the example below.

www-linux.gsi.de/~go4/HOWTOthreads/howtothreadsbody.html#tth_sEc8

Loading:

Start an interactive ROOT session

Load the shared library:

```
root [] gSystem->Load("mhs3.so");
```

Or

```
root [] gSystem->Load("CalcPiThread.so");
```

Creating:

Create a thread instance (see also example `RunMhs3.C` or `RunPi.C`) with:

```
root [] TThread *th = new TThread(UserFun,UserArgs);
```

When called from the interpreter, this gives the name "`UserFun`" to the thread. This name can be used to retrieve the thread later. However, when called from compiled code, this method does not give any name to the thread. So give a name to the thread in compiled use:

```
root [] TThread *th = new TThread("MyThread", UserFun, UserArgs);
```

You can pass arguments to the thread function using the `UserArgs`-pointer. When you want to start a method of a class as a thread, you have to give the pointer to the class instance as `UserArgs`.

Running:

```
root [] th->Run();
root [] TThread::Ps(); // like UNIX ps c.ommand;
```

With the `mhs3` example, you should be able to see a canvas with two pads on it. Both pads keep histograms updated and filled by three different threads.

With the `CalcPi` example, you should be able to see two threads calculating Pi with the given number of intervals as precision.

TThread in More Detail

CINT is not thread safe yet, and it will block the execution of the threads until it has finished executing.

Asynchronous Actions

Different threads can work simultaneously with the same object. Some actions can be dangerous. For example, when two threads create a histogram object, ROOT allocates memory and puts them to the same collection. If it happens at the same time, the results are undetermined. To avoid this problem, the user has to synchronize these actions with:

```
TThread::Lock()     // Locking the following part of code
...                 // Create an object, etc...
TThread::UnLock()   // Unlocking
```

The code between `Lock()` and `UnLock()` will be performed uninterrupted. No other threads can perform actions or access objects/collections while it is being executed. The `TThread::Lock()` and `TThread::UnLock()` methods internally use a global `TMutex` instance for locking. The user may also define his own `TMutex MyMutex` instance and may locally protect his asynchronous actions by calling `MyMutex.Lock()` and `MyMutex.UnLock()`.

Synchronous Actions: TCondition

To synchronize the actions of different threads you can use the `TCondition` class, which provides a signaling mechanism.

The `TCondition` instance must be accessible by all threads that need to use it, i.e. it should be a global object (or a member of the class which owns the threaded methods, see below). To create a `TCondition` object, a `TMutex` instance is required for the `Wait` and `TimedWait` locking methods. One can pass the address of an external mutex to the `TCondition` constructor:

```
TMutex MyMutex;
TCondition MyCondition(&MyMutex);
```

If `zero` is passed, `TCondition` creates and uses its own internal mutex:

```
TCondition MyCondition(0);
```

You can now use the following methods of synchronization:

- `TCondition::Wait()` waits until any thread sends a signal of the same condition instance: `MyCondition.Wait()` reacts on `MyCondition.Signal()` or `MyCondition.Broadcast()`. `MyOtherCondition.Signal()` has no effect.
- If several threads wait for the signal from the same `TCondition MyCondition`, at `MyCondition.Signal()` only one thread will react; to activate a further thread another `MyCondition.Signal()` is required, etc.
- If several threads wait for the signal from the same `TCondition MyCondition`, at `MyCondition.Broadcast()` all threads waiting for `MyCondition` are activated at once.

In some tests of `MyCondition` using an internal mutex, `Broadcast()` activated only one thread (probably depending whether `MyCondition` had been signaled before).

- `MyCondition.TimedWait(secs,nanosecs)` waits for `MyCondition` until the *absolute* time in seconds and nanoseconds since beginning of the epoch (January, 1st, 1970) is reached; to use relative timeouts ``delta'', it is required to calculate the absolute time at the beginning of waiting ``now''; for example:

```
Ulong_t now,then,delta;               // seconds
TDatime myTime;                       // root daytime class
myTime.Set();                         // myTime set to "now"
now=myTime.Convert();                 // to seconds since 1970
then=now+delta;                       // absolute timeout
wait=MyCondition.TimedWait(then,0);  // waiting
```

- Return value wait of `MyCondition.TimedWait` should be 0, if `MyCondition.Signal()` was received, and should be nonzero, if timeout was reached.

The conditions example shows how three threaded functions are synchronized using `TCondition`: a ROOT script `condstart.C` starts the threads, which are defined in a shared library (`conditions.cxx`, `conditions.h`).

Xlib connections

Usually `Xlib` is not thread safe. This means that calls to the X could fail, when it receives X-messages from different threads. The actual result depends strongly on which version of `Xlib` has been installed on your system. The only thing we can do here within ROOT is calling a special function `XInitThreads()` (which is part of the `Xlib`), which should (!) prepare the `Xlib` for the usage with threads.

To avoid further problems within ROOT some redefinition of the `gPad` pointer was done (that's the main reason for the recompilation). When a thread creates a `TCanvas`, this object is actually created in the main thread; this should be transparent to the user. Actions on the canvas are controlled via a function, which returns a pointer to either thread specific data (TSD) or the main thread pointer. This mechanism works currently only for `gPad` and will soon be implemented for other global Objects as e.g. `gVirtualX`, `gDirectory`, `gFile`.

Canceling a TThread

Canceling of a thread is a rather dangerous action. In `TThread` canceling is forbidden by default. The user can change this default by calling `TThread::SetCancelOn()`. There are two cancellation modes:

Deferred

Set by `TThread::SetCancelDeferred()` (default): When the user knows safe places in his code where a thread can be canceled without risk for the rest of the system, he can define these points by invoking `TThread::CancelPoint()`. Then, if a thread is canceled, the cancellation is deferred up to the call of `TThread::CancelPoint()` and then the thread is canceled safely. There are some default cancel points for `pthreads` implementation, e.g. any call of `TCondition::Wait()`, `TCondition::TimedWait()`, `TThread::Join()`.

Asynchronous

Set by `TThread::SetCancelAsynchronous()`: If the user is sure that his application is cancel safe, he could call:

```
TThread::SetCancelAsynchronous();
TThread::SetCancelOn();
// Now cancelation in any point is allowed.
...
...
// Return to default
TThread::SetCancelOff();
TThread::SetCancelDeferred();
```

To cancel a thread `TThread* th` call:

```
Th->Kill();
```

To cancel by thread name:

```
TThread::Kill(name);
```

To cancel a thread by ID:

```
TThread::Kill(tid);
```

To cancel a thread and delete `th` when cancel finished:

```
Th->Delete();
```

Deleting of the thread instance by the operator delete is dangerous. Use `th->Delete()` instead. C++ delete is safe only if thread is not running.

Often during the canceling, some clean up actions must be taken. To define clean up functions use:

```
void UserCleanUp(void *arg){
      // here the user cleanup is done
      ...
}

TThread::CleanUpPush(&UserCleanUp,arg);
       // push user function into cleanup stack
       // "last in, first out"

TThread::CleanUpPop(1); // pop user function out of stack
                        // and execute it,
                        // thread resumes after this call

TThread::CleanUpPop(0); // pop user function out of stack
                        // _without_ executing it
```

Note: `CleanUpPush` and `CleanUpPop` should be used as corresponding pairs like brackets; unlike `pthreads` cleanup stack (which is *not* implemented here), `TThread` does not force this usage.

Finishing thread

When a thread returns from a user function the thread is finished. It also can be finished by `TThread::Exit()`. Then, in case of pthread-detached mode, the thread vanishes completely.

By default, on finishing `TThread` executes the most recent cleanup function (`CleanUpPop(1)` is called automatically once).

Advanced TThread: Launching a Method in a Thread

Consider a class `Myclass` with a member function `void* Myclass::Thread0((void* arg)` that shall be launched as a thread. To start `Thread0` as a `TThread`, class `Myclass` may provide a method:

```
Int_t Myclass::Threadstart(){
 if(!mTh){
     mTh= new TThread("memberfunction",
                      (void(*) (void *))&Thread0,
                      (void*) this);
     mTh->Run();
     return 0;
     }
 return 1;
}
```

Here `mTh` is a `TThread*` pointer which is member of `Myclass` and should be initialized to 0 in the constructor. The `TThread` constructor is called as when we used a plain C function above, except for the following two differences.

First, the member function `Thread0` requires an explicit cast to `(void(*) (void *))`. This may cause an annoying but harmless compiler warning:

```
Myclass.cxx:98: warning: converting from "void
(Myclass::*)(void *)" to "void *" )
```

Strictly speaking, `Thread0` must be a static member function to be called from a thread. Some compilers, for example `gcc` version 2.95.2, may not allow the `(void(*) (void*))s` cast and just stop if `Thread0` is not static. On the other hand, if `Thread0` is static, no compiler warnings are generated at all.

Because the `'this'` pointer is passed in `'arg'` in the call to `Thread0(void *arg)`, you have access to the instance of the class even if `Thread0` is static. Using the `'this'` pointer, non static members can still be read and written from `Thread0`, as long as you have provided Getter and Setter methods for these members.

For example:

```
Bool_t state = arg->GetRunStatus();
arg->SetRunStatus(state);
```

Second, the pointer to the current instance of `Myclass`, i.e. `(void*) this`, has to be passed as first argument of the threaded function `Thread0` (C++ member functions internally expect the this pointer as first argument to have access to class members of the same instance). `pthreads` are made for simple C functions and do not know about `Thread0` being a member function of a class. Thus, you have to pass this information by hand, if you want to access all members of the `Myclass` instance from the `Thread0` function.

Note: Method `Thread0` cannot be a virtual member function, since the cast of `Thread0` to `void(*)` in the `TThread` constructor may raise problems with C++ virtual function table. However, `Thread0` may call another virtual member function `virtual void Myclass::Func0()` which then can be overridden in a derived class of `Myclass`. (See example `TMhs3`).

Class `Myclass` may also provide a method to stop the running thread:

```
Int_t Myclass::Threadstop(){
 if(mTh){
        TThread::Delete(mTh);
        delete mTh;
        mTh=0;
        return 0;
 }
 return 1;
}
```

Example *TMhs3*: Class `TThreadframe` (`TThreadframe.h`, `TThreadframe.cxx`) is a simple example of a framework class managing up to four threaded methods. Class `TMhs3` (`TMhs3.h, TMhs3.cxx`) inherits from this base class, showing the *mhs3* example 8.1 (*mhs3.h*, *mhs3.cxx*) within a class.

The `Makefile` of this example builds the shared libraries `libTThreadframe.so` and `libTMhs3.so`. These are either loaded or executed by the ROOT script `TMhs3demo.C`, or are linked against an executable: `TMhs3run.cxx`.

Known Problems

Parts of the ROOT framework, like the interpreter, are not yet thread-safe. Therefore, you should use this package with caution. If you restrict your threads to distinct and `simple' duties, you will able to benefit from their use.

The `TThread` class is available on all platforms, which provide a POSIX compliant thread implementation. On Linux, Xavier Leroy's Linux Threads implementation is widely used, but the `TThread` implementation should be usable on all platforms that provide `pthread`.

Linux Xlib on SMP machines is not yet thread-safe. This may cause crashes during threaded graphics operations; this problem is independent of ROOT.

Object instantiation: there is no implicit locking mechanism for memory allocation and global ROOT lists. The user has to explicitly protect his code when using them.

Glossary

The following glossary is adapted from the description of the Rogue Wave Threads.h++ package.

Process

A process is a program that is loaded into memory and prepared for execution. Each process has a private address space. Processes begin with a single thread.

Thread

A thread of control, or more simply, a thread, is a sequence of instructions being executed in a program. A thread has a program counter and a private stack to keep track of local variables and return addresses. A multithreaded process is associated with one or more threads. Threads execute independently. All threads in a given process share the private address space of that process.

Concurrency

Concurrency exists when at least two threads are in progress at the same time. A system with only a single processor can support concurrency by switching execution contexts among multiple threads.

Parallelism

Parallelism arises when at least two threads are executing simultaneously. This requires a system with multiple processors. Parallelism implies concurrency, but not vice-versa.

Reentrant

A function is reentrant if it will behave correctly even if a thread of execution enters the function while one or more threads are already executing within the function. These could be the same thread, in the case of recursion, or different threads, in the case of concurrency.

Thread-specific data

Thread-specific data (TSD) is also known as thread-local storage (TLS). Normally, any data that has lifetime beyond the local variables on the thread's private stack are shared among all threads within the process. Thread-specific data is a form of static or global data that is maintained on a per-thread basis. That is, each thread gets its own private copy of the data.

Synchronization

Left to their own devices, threads execute independently. Synchronization is the work that must be done when there are, in fact, interdependencies that require some form of communication among threads. Synchronization tools include mutexes, semaphores, condition variables, and other variations on locking.

Critical Section

A critical section is a section of code that accesses a non-sharable resource. To ensure correct code, only one thread at a time may execute in a critical section. In other words, the section is not reentrant.

Mutex

A mutex, or mutual exclusion lock, is a synchronization object with two states locked and unlocked. A mutex is usually used to ensure that only one thread at a time executes some critical section of code. Before entering a critical section, a thread will attempt to lock the mutex, which guards that section. If the mutex is already locked, the thread will block until the mutex is unlocked, at which time it will lock the mutex, execute the critical section, and unlock the mutex upon leaving the critical section.

Semaphore

A semaphore is a synchronization mechanism that starts out initialized to some positive value. A thread may ask to wait on a semaphore in which case the thread blocks until the value of the semaphore is positive. At that time the semaphore count is decremented and the thread continues. When a thread releases semaphore, the semaphore count is incremented. Counting semaphores are useful for coordinating access to a limited pool of some resource.

Readers/Writer Lock

A multiple-readers, single-writer lock is one that allows simultaneous read access by many threads while restricting write access to only one thread at a time. When any thread holds the lock for reading, other threads can also acquire the lock reading. If one thread holds the lock for writing, or is waiting to acquire the lock for writing, other threads must wait to acquire the lock for either reading or writing.

Condition Variable

Use a condition variable in conjunction with a mutex lock to automatically block threads until a particular condition is true.

Multithread safe levels

A possible classification scheme to describe thread-safety of libraries:

- All public and protected functions are reentrant. The library provides protection against multiple threads trying to modify static and global data used within a library. The developer must explicitly lock access to objects shared between threads. No other thread can write to a locked object unless it is unlocked. The developer needs to lock local objects. The spirit, if not the letter of this definition requires the user of the library only to be familiar with the semantic content of the objects in use. Locking access to objects that are being shared due to extra-semantic details of implementation (for example, copy-on-write) should remain the responsibility of the library.
- All public and protected functions are reentrant. The library provides protection against multiple threads trying to modify static and global data used within the library. The preferred way of providing this protection is to use mutex locks. The library also locks an object before writing to it. The developer is not required to explicitly lock or unlock a class object (static, global or local) to perform a single operation on the object. Note that even multithread safe level II hardly relieves the user of the library from the burden of locking.

Deadlock

A thread suffers from deadlock if it is blocked waiting for a condition that will never occur. Typically, this occurs when one thread needs to access a resource that is already locked by another thread, and that other thread is trying to access a resource that has already been locked by the first thread. In this situation, neither thread is able to progress; they are deadlocked.

Multiprocessor

A multiprocessor is a hardware system with multiple processors or multiple, simultaneous execution units.

List of Example files

Here is a list of the examples that you can find on the thread authors' web site (Jörn Adamczewski, Marc Hemberger) at:

www-linux.gsi.de/~go4/HOWTOthreads/howtothreadsbody.html#tth_sEc8

Example mhs3

- Makefile.mhs3
- mhs3.h
- mhs3LinkDef.h
- mhs3.cxx
- rootlogon.C
- RunMhs3.C

Example conditions

- Makefile.conditions
- conditions.h
- conditionsLinkDef.h
- conditions.cxx
- condstart.C

Example TMhs3

- Makefile.TMhs3
- TThreadframe.h
- TThreadframeLinkDef.h
- TThreadframe.cxx
- TMhs3.h
- TMhs3LinkDef.h
- TMhs3.cxx
- TMhs3run.cxx
- TMhs3demo.C

Example CalcPiThread

- Makefile.CalcPiThread
- CalcPiThread.h
- CalcPiThreadLinkDef.h
- CalcPiThread.cxx
- rootlogon.C
- RunPi.C

21 Appendix A: Install and Build ROOT

ROOT Copyright and Licensing Agreement:

This is a reprint of the copyright and licensing agreement of ROOT:

Installing ROOT

To install ROOT you will need to go to the ROOT website at: http://root.cern.ch/root/Availability.html

You have a choice to download the binaries or the source. The source is quicker to transfer since it is only 3.4 MB, but you will need to compile and link it. The binaries range from 7.4 MB to 11 MB depending on the target platform.

Choosing a Version

The ROOT developers follow the principle of "release early and release often", however a very large portion of a user base requires a stable product therefore generally three versions of the system is available for download – new, old and pro:

- The new version evolves quickly, with weekly or bi-weekly releases. Use this to get access to the latest and greatest, but it may not be stable. By trying out the new version you can help us converge quickly to a stable version that can then become the new pro version. If you are a new user we would advice you to try the new version.
- The pro (production) version is a version we feel comfortable with to exposing to a large audience for serious work. The change rate of this version is much lower than for the new version, it is about 3 to 6 months.
- The old version is the previous pro version that people might need for some time before switching the new pro version. The old change rate is the same as for pro.

Supported Platforms

For each of the three versions the full source is available for these platforms. Precompiled binaries are also provided for most of them:

- `Intel x86 Linux (g++, egcs and KAI/KCC)`
- `Intel Itanium Linux (g++)`
- `HP HP-UX 10.x (HP CC and aCC, egcs1.1 C++ compilers)`
- `IBM AIX 4.1 (xlc compiler and egcs1.2)`
- `Sun Solaris for SPARC (SUN C++ compiler and egcs)`
- `Sun Solaris for x86 (SUN C++ compiler)`
- `Sun Solaris for x86 KAI/KCC`
- `Compaq Alpha OSF1 (egcs1.2 and DEC/CXX)`
- `Compaq Alpha Linux (egcs1.2)`
- `SGI Irix (g++, KAI/KCC and SGI C++ compiler)`
- `Windows NT and Windows95 (Visual C++ compiler)`
- `Mac MkLinux and Linux PPC (g++)`
- `Hitachi HI-UX (egcs)`
- `LynxOS`
- `MacOS (CodeWarrior, no graphics)`

Installing Precompiled Binaries

The binaries are available for downloading from

root.cern.ch/root/Availability.html.

Once downloaded you need to unzip and de-tar the file. For example, if you have downloaded ROOT v2.25 for HPUX:

```
% gunzip root_v2.25.00.HP-UX.B.10.20.tar.gz
% tar xvf root_v2.25.00.HP-UX.B.10.20.tar
```

This will create the directory root. Before getting started read the file README/README. Also, read the Introduction chapter for an explanation of the directory structure.

Installing the Source

You have a choice to download a compressed (tar ball) file containing the source, or you can login to the source code change control (CVS) system and check out the most recent source. The compressed file is a one time only choice; every time you would like to upgrade you will need to download the entire new version. Choosing the CVS option will allow you to get changes as they are submitted by the developers and you can stay up to date.

Installing and Building the source from a compressed file

To install the ROOT source you can download the tar file containing all the source files from the ROOT website. The first thing you should do is to get the latest version as a tar file. Unpack the source tar file, this creates directory 'root':

```
% tar zxvf root_v2.25.xx.source.tar.gz
```

Set `ROOTSYS` to the directory where you want root to be installed:

```
% export ROOTSYS=<path>/root
```

Now type the build commands:

```
% cd root
% ./configure --help
% ./configure <target>
% gmake
% gmake install
```

Add `$ROOTSYS/bin` to `PATH` and `$ROOTSYS/lib to LD_LIBRARY_PATH`:

```
% export PATH=$ROOTSYS/bin:$PATH
% export LD_LIBRARY_PATH=$ROOTSYS/lib:$LD_LIBRARY_PATH
```

Try running root:

```
% root
```

It is also possible to setup and build ROOT in a fixed location. Please check README/INSTALL for more a detailed description of this procedure.

Target directory

By default, ROOT will be built in the $ROOTSYS directory. In that case the whole system (binaries, sources, tutorials, etc.) will be located under the $ROOTSYS directory.

`Makefile` targets

The `Makefile` is documented in details in the README/BUILDSYSTEM file. It explains the build options and targets.

More Build Options

To build the library providing thread support you need to define either the environment variable '`THREAD=-lpthread`' or the `configure` flag '`--with-thread=-lpthread`' (it is the default for the `linuxegcs` architecture). [Note: this is only tested on Linux for the time being.]

To build the library providing CERN RFIO (remote I/O) support you need to define either the environment variable '`RFIO=<path>/libshift.a`' or the `configure` flag '`--with-rfio=<path>/libshift.a`'. For pre-built version of `libshift.a` see ftp://root.cern.ch/root/shift/)

To build the PAW and Geant3 conversion programs `h2root` and `g2root` you need to define either the environment variable '`CERNLIB=<cernlibpath>`' or the `configure` flag '`--with-cern-libdir=<cernlibpath>`'.

To build the MySQL interface library you need to install MySQL first. Visit http://www.mysql.com/ for the latest versions.

To build the strong authentication module used by `rootd`, you first have to install the SRP (Secure Remote Password) system. Visit http://jafar.stanford.edu/srp/index.html.

To use the library you have to define either the environment variable '`SRP=<srpdir>`' or the `configure` flag '`--with-srp=<srpdir>`'.

To build the event generator interfaces for Pythia and Pythia6, you first have to get the pythia libraries available from ftp: ftp://root.cern.ch/root/pythia/.

To use the libraries you have to define either '`PYTHIA=<pythiadir>`' or the `configure` flag '`--with-pythia=<pythiadir>`'. The same applies for Pythia6.

Installing the Source from CVS

This paragraph describes how to checkout and build ROOT from CVS for Unix systems. For description of a checkout for other platforms, please see ROOT installation web page (http://root.cern.ch/root/CVS.html).

(Note: The syntax is for `ba(sh)`, if you use a `t(csh)` then you have to substitute `export` with `setenv`.)

```
% export CVSROOT=:pserver:cvs@root.cern.ch:/user/cvs
% cvs login
% (Logging in to cvs@root.cern.ch)
% CVS password: cvs
% cvs –z3 checkout root
U root/…
U …
% cd root
% ./configure --help
% ./configure <platform>
% gmake
```

If you are a part of a collaboration, you may need to use setup procedures specific to the particular development environment prior to running `gmake`.

You only need to run `cvs` login once. It will remember anonymous password in your `$HOME/.cvspass` file. For more install instructions and options, see the file README/INSTALL.

CVS for Windows

Although there exists a native version of CVS for Windows, we only support the build process under the Cygwin environment. You must have CVS version 1.10 or newer.

The checkout and build procedure is similar to that for Unix.For detailed install instructions, see the file REAMDE/INSTALL.

Converting a tar ball to a working CVS sandbox

You may want to consider downloading the source as a tar ball and converting it to CVS because it is faster to download the tar ball than checking out the entire source with CVS. Our source tar ball contains CVS information. If your tar ball is dated June 1, 2000 or later, it is already set up to talk to our public server (root.cern.ch). You just need to download and unpack the tar ball and then run following commands:

```
% cd root
% cvs -z3 update -d -P
% ./configure <platform>
```

Staying up-to-date

To keep your local ROOT source up-to-date with the CVS repository you should regularly run the command:

```
% cvs -z3 update -d –P
```

Setting the Environment Variables

Before you can run ROOT you need to set the environment variable `ROOTSYS` and change your path to include `root/bin` and library path variables to include `root/lib`. Please note: The syntax is for `ba(sh)`, if you are running `t(csh)` you will have to use `setenv` and `set` instead of `export.`

1. Define the variable $ROOTSYS to the directory where you unpacked the ROOT:

```
% export ROOTSYS=/root
```

2. Add ROOTSYS/bin to your PATH:

```
% export PATH=$PATH:$ROOTSYS/bin
```

3. Set the Library Path

On HP-UX, before executing the interactive module, you must set the library path:

```
% export SHLIB_PATH=$SHLIB_PATH:$ROOTSYS/lib
```

On AIX, before executing the interactive module, you must set the library path:

```
% [ -z "$LIBPATH" ] && export LIBPATH=/lib:/usr/lib
% export LIBPATH=$LIBPATH:$ROOTSYS/lib
```

On Linux, Solaris, Alpha OSF and SGI, before executing the interactive module, you must set the library path:

```
% export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:$ROOTSYS/lib
```

On Solaris, in case your LD_LIBRARY_PATH is empty, you should set it like this:

```
% export
LD_LIBRARY_PATH=$LD_LIBRARY_PATH:$ROOTSYS/lib:/usr/dt/lib
```

`ROOTSYS` is an environment variable pointing to the ROOT directory. For example, if you use the HPUX-10 AFS version you should set:

```
% export
ROOTSYS=/afs/cern.ch/na49/library.4/ROOT/v2.23/hp700_ux102/
root
```

To run the program just type: `root`

Documentation to Download

PostScript Documentation

The following PostScript files have been generated by automatically scanning the ROOT HMTL files. This documentation includes page numbers, table of contents and an index.

- The latest revision of the Users Guide (5MB, 350 pages): http://root.cern.ch/root/RootDoc.html
- ROOT Overview: Overview of the ROOT system (365 KB, 81 pages) ftp://root.cern.ch/root/ROOTMain.ps.gz
- ROOT Tutorials: The ROOT tutorials with graphics examples (320 KB, 81 pages) ftp://root.cern.ch/root/ROOTTutorials.ps.gz
- ROOT Classes: Description of all the ROOT classes (1.47 MB, 661 pages) ftp://root.cern.ch/root/ROOTClasses.ps.gz

HTML Documentation

In case you only have access to a low-speed connection to CERN, you can get a copy of the complete ROOT html tree (24 MB):

ftp://root.cern.ch/root/ROOTHtmlDoc.ps.gz.

22 Appendix B: Event.h

```
class EventHeader {
private:
   Int_t        fEvtNum;
   Int_t        fRun;
   Int_t        fDate;
   Int_t        fN;
public:
   EventHeader() : fEvtNum(0), fRun(0), fDate(0) { }
   virtual ~EventHeader() { }
   void   Set( Int_t i, Int_t r, Int_t d) { fEvtNum = i;
   fRun = r; fDate = d; }
   Int_t  GetEvtNum() const { return fEvtNum; }
   Int_t  GetRun() const { return fRun; }
   Int_t  GetDate() const { return fDate; }

   ClassDef (EventHeader,1)  //Event Header
};


class Event : public TObject {
private:
   Int_t          fNtrack;
   Int_t          fNseg;
   Int_t          fNvertex;
   UInt_t         fFlag;
   Float_t        fTemperature;
   EventHeader    fEvtHdr;
   TClonesArray  *fTracks;
   TH1F          *fH;
    static TClonesArray *fgTracks;
   static TH1F         *fgHist;

public:
   Event();
   virtual ~Event();
   void          Clear(Option_t *option ="");
   static void   Reset(Option_t *option ="");
   void          ResetHistogramPointer() {fH=0;}
   void          SetNseg(Int_t n) { fNseg = n; }
   void          SetNtrack(Int_t n) { fNtrack = n; }
   void          SetNvertex(Int_t n) { fNvertex = n; }
   void          SetFlag(UInt_t f) { fFlag = f; }
   void          SetTemperature(Float_t t) { fTemperature = t; }
   void          SetHeader( Int_t i, Int_t run, Int_t date,
                            Float_t random);
   void          AddTrack(Float_t random);
   Int_t         GetNtrack() const { return fNtrack; }
   Int_t         GetNseg() const { return fNseg; }
```

```
   Int_t         GetNvertex() const { return fNvertex; }
   UInt_t        GetFlag() const { return fFlag; }
   Float_t       GetTemperature() const { return fTemperature; }
   EventHeader  *GetHeader() { return &fEvtHdr; }
   TClonesArray *GetTracks() const { return fTracks; }
   TH1F         *GetHistogram() const { return fH; }

   ClassDef (Event,1)  //Event structure
};


class Track : public TObject {
private:
   Float_t      fPx;           //X component of the momentum
   Float_t      fPy;           //Y component of the momentum
   Float_t      fPz;           //Z component of the momentum
   Float_t      fRandom;       //A random track quantity
   Float_t      fMass2;        //The mass square of this particle
   Float_t      fBx;           //X intercept at the vertex
   Float_t      fBy;           //Y intercept at the vertex
   Float_t      fMeanCharge;   //Mean charge deposition of all hits
   Float_t      fXfirst;       //X coordinate of the first point
   Float_t      fXlast;        //X coordinate of the last point
   Float_t      fYfirst;       //Y coordinate of the first point
   Float_t      fYlast;        //Y coordinate of the last point
   Float_t      fZfirst;       //Z coordinate of the first point
   Float_t      fZlast;        //Z coordinate of the last point
   Float_t      fCharge;       //Charge of this track
   Int_t        fNpoint;       //Number of points for this track
   Short_t      fValid;        //Validity criterion

public:
   Track() { }
   Track(Float_t random);
   virtual ~Track() { }
   Float_t       GetPx() const { return fPx; }
   Float_t       GetPy() const { return fPy; }
   Float_t       GetPz() const { return fPz; }
   Float_t       GetPt() const { return
                         TMath::Sqrt(fPx*fPx+ fPy*fPy); }
   Float_t       GetRandom() const { return fRandom; }
   Float_t       GetBx() const { return fBx; }
   Float_t       GetBy() const { return fBy; }
   Float_t       GetMass2() const { return fMass2; }
   Float_t       GetMeanCharge() const { return fMeanCharge; }
   Float_t       GetXfirst() const { return fXfirst; }
   Float_t       GetXlast()  const { return fXlast; }
   Float_t       GetYfirst() const { return fYfirst; }
   Float_t       GetYlast()  const { return fYlast; }
   Float_t       GetZfirst() const { return fZfirst; }
   Float_t       GetZlast()  const { return fZlast; }
   Float_t       GetCharge() const { return fCharge; }
   Int_t         GetNpoint() const { return fNpoint; }
   Short_t       GetValid()  const { return fValid; }
   virtual void  SetValid(Int_t valid=1) { fValid = valid; }

   ClassDef (Track,1)  //A track segment
};


class HistogramManager {

private:
   TH1F  *fNtrack;
```

```
   TH1F  *fNseg;
   TH1F  *fTemperature;
   TH1F  *fPx;
   TH1F  *fPy;
   TH1F  *fPz;
   TH1F  *fRandom;
   TH1F  *fMass2;
   TH1F  *fBx;
   TH1F  *fBy;
   TH1F  *fMeanCharge;
   TH1F  *fXfirst;
   TH1F  *fXlast;
   TH1F  *fYfirst;
   TH1F  *fYlast;
   TH1F  *fZfirst;
   TH1F  *fZlast;
   TH1F  *fCharge;
   TH1F  *fNpoint;
   TH1F  *fValid;

public:
   HistogramManager(TDirectory *dir);
   virtual ~HistogramManager();
   void Hfill(Event *event);
   ClassDef (HistogramManager,1)  //Manages all histograms
};

#endif
```

23 Appendix C: SplitClass

```
//////////////////////////////////////////////////////////
//   This class has been automatically generated
//     (Wed Apr 12 12:04:05 2000 by ROOT version 2.24/02)
//   from TTree T/An example of a ROOT tree
//   found on file: Event.root
//////////////////////////////////////////////////////////


#ifndef SplitClass_h
#define SplitClass_h

#if !defined(__CINT__) || defined(__MAKECINT__)
#include <TTree.h>
#include <TFile.h>
#endif
   const Int_t kMaxfTracks = 1000;

class SplitClass {
   public :
   TTree          *fTree;  //pointer to the analyzed TTree or TChain
   TTree          *fCurrent; //pointer to the current TTree
//Declaration of leaves types
   Int_t           fNtrack;
   Int_t           fNseg;
   Int_t           fNvertex;
   UInt_t          fFlag;
   Float_t         fTemperature;
   Int_t           fEvtHdr_fEvtNum;
   Int_t           fEvtHdr_fRun;
   Int_t           fEvtHdr_fDate;
   Int_t           fTracks_;
   Float_t         fTracks_fPx[kMaxfTracks];
   Float_t         fTracks_fPy[kMaxfTracks];
   Float_t         fTracks_fPz[kMaxfTracks];
   Float_t         fTracks_fRandom[kMaxfTracks];
   Float_t         fTracks_fMass2[kMaxfTracks];
   Float_t         fTracks_fBx[kMaxfTracks];
   Float_t         fTracks_fBy[kMaxfTracks];
   Float_t         fTracks_fMeanCharge[kMaxfTracks];
   Float_t         fTracks_fXfirst[kMaxfTracks];
   Float_t         fTracks_fXlast[kMaxfTracks];
   Float_t         fTracks_fYfirst[kMaxfTracks];
   Float_t         fTracks_fYlast[kMaxfTracks];
   Float_t         fTracks_fZfirst[kMaxfTracks];
   Float_t         fTracks_fZlast[kMaxfTracks];
   Float_t         fTracks_fCharge[kMaxfTracks];
   Int_t           fTracks_fNpoint[kMaxfTracks];
   Short_t         fTracks_fValid[kMaxfTracks];
   UInt_t          fTracks_fUniqueID[kMaxfTracks];
   UInt_t          fTracks_fBits[kMaxfTracks];
```

```
   TH1F            *fH;
   UInt_t          fUniqueID;
   UInt_t          fBits;

//List of branches
   TBranch        *b_event;
   TBranch        *b_fNtrack;
   TBranch        *b_fNseg;
   TBranch        *b_fNvertex;
   TBranch        *b_fFlag;
   TBranch        *b_fTemperature;
   TBranch        *b_fEvtHdr_fEvtNum;
   TBranch        *b_fEvtHdr_fRun;
   TBranch        *b_fEvtHdr_fDate;
   TBranch        *b_fTracks_;
   TBranch        *b_fTracks_fPx;
   TBranch        *b_fTracks_fPy;
   TBranch        *b_fTracks_fPz;
   TBranch        *b_fTracks_fRandom;
   TBranch        *b_fTracks_fMass2;
   TBranch        *b_fTracks_fBx;
   TBranch        *b_fTracks_fBy;
   TBranch        *b_fTracks_fMeanCharge;
   TBranch        *b_fTracks_fXfirst;
   TBranch        *b_fTracks_fXlast;
   TBranch        *b_fTracks_fYfirst;
   TBranch        *b_fTracks_fYlast;
   TBranch        *b_fTracks_fZfirst;
   TBranch        *b_fTracks_fZlast;
   TBranch        *b_fTracks_fCharge;
   TBranch        *b_fTracks_fNpoint;
   TBranch        *b_fTracks_fValid;
   TBranch        *b_fTracks_fUniqueID;
   TBranch        *b_fTracks_fBits;
   TBranch        *b_fH;
   TBranch        *b_fUniqueID;
   TBranch        *b_fBits;

   SplitClass(TTree *tree=0);
   ~SplitClass();
   Int_t GetEntry(Int_t entry);
   Int_t LoadTree(Int_t entry);
   void  Init(TTree *tree);
   void  Loop();
   void  Notify();
   void Show(Int_t entry = -1);
};

#endif

#ifdef SplitClass_cxx
SplitClass::SplitClass(TTree *tree)
{
// if parameter tree is not specified (or zero),connect the
// file used to generate this class and read the Tree.
   if (tree == 0) {
      TFile *f = (TFile*)gROOT->GetListOfFiles()->FindObject("Event.root");
      if (!f) {
         f = new TFile("Event.root");
      }
      tree = (TTree*)gDirectory->Get("T");

   }
   Init(tree);
}

SplitClass::~SplitClass()
{
```

```
   if (!fTree) return;
   delete fTree->GetCurrentFile();
}


Int_t SplitClass::GetEntry(Int_t entry)
{
// Read contents of entry.
   if (!fTree) return 0;
   return fTree->GetEntry(entry);
}

Int_t SplitClass::LoadTree(Int_t entry)
{
// Set the environment to read one entry
   if (!fTree) return -5;
   Int_t centry = fTree->LoadTree(entry);
   if (centry < 0) return centry;
   if (fTree->GetTree() != fCurrent) {
      fCurrent = fTree->GetTree();
      Notify();
   }
   return centry;
}

void SplitClass::Init(TTree *tree)
{
//   Set branch addresses
   if (tree == 0) return;
   fTree    = tree;
   fCurrent = 0;

   fTree->SetBranchAddress("event",(void*)-1);
   fTree->SetBranchAddress("fNtrack",&fNtrack);
   fTree->SetBranchAddress("fNseg",&fNseg);
   fTree->SetBranchAddress("fNvertex",&fNvertex);
   fTree->SetBranchAddress("fFlag",&fFlag);
   fTree->SetBranchAddress("fTemperature",&fTemperature);
   fTree->SetBranchAddress("fEvtHdr.fEvtNum",&fEvtHdr_fEvtNum);
   fTree->SetBranchAddress("fEvtHdr.fRun",&fEvtHdr_fRun);
   fTree->SetBranchAddress("fEvtHdr.fDate",&fEvtHdr_fDate);
   fTree->SetBranchAddress("fTracks_",&fTracks_);
   fTree->SetBranchAddress("fTracks.fPx",fTracks_fPx);
   fTree->SetBranchAddress("fTracks.fPy",fTracks_fPy);
   fTree->SetBranchAddress("fTracks.fPz",fTracks_fPz);
   fTree->SetBranchAddress("fTracks.fRandom",fTracks_fRandom);
   fTree->SetBranchAddress("fTracks.fMass2",fTracks_fMass2);
   fTree->SetBranchAddress("fTracks.fBx",fTracks_fBx);
   fTree->SetBranchAddress("fTracks.fBy",fTracks_fBy);
   fTree->SetBranchAddress("fTracks.fMeanCharge",fTracks_fMeanCharge);
   fTree->SetBranchAddress("fTracks.fXfirst",fTracks_fXfirst);
   fTree->SetBranchAddress("fTracks.fXlast",fTracks_fXlast);
   fTree->SetBranchAddress("fTracks.fYfirst",fTracks_fYfirst);
   fTree->SetBranchAddress("fTracks.fYlast",fTracks_fYlast);
   fTree->SetBranchAddress("fTracks.fZfirst",fTracks_fZfirst);
   fTree->SetBranchAddress("fTracks.fZlast",fTracks_fZlast);
   fTree->SetBranchAddress("fTracks.fCharge",fTracks_fCharge);
   fTree->SetBranchAddress("fTracks.fNpoint",fTracks_fNpoint);
   fTree->SetBranchAddress("fTracks.fValid",fTracks_fValid);
   fTree->SetBranchAddress("fTracks.fUniqueID",fTracks_fUniqueID);
   fTree->SetBranchAddress("fTracks.fBits",fTracks_fBits);
   fTree->SetBranchAddress("fH",&fH);
   fTree->SetBranchAddress("fUniqueID",&fUniqueID);
   fTree->SetBranchAddress("fBits",&fBits);
}

void SplitClass::Notify()
{
```

```
//   called by LoadTree when loading a new file
//   get branch pointers
   b_event = fTree->GetBranch("event");
   b_fNtrack = fTree->GetBranch("fNtrack");
   b_fNseg = fTree->GetBranch("fNseg");
   b_fNvertex = fTree->GetBranch("fNvertex");
   b_fFlag = fTree->GetBranch("fFlag");
   b_fTemperature = fTree->GetBranch("fTemperature");
   b_fEvtHdr_fEvtNum = fTree->GetBranch("fEvtHdr.fEvtNum");
   b_fEvtHdr_fRun = fTree->GetBranch("fEvtHdr.fRun");
   b_fEvtHdr_fDate = fTree->GetBranch("fEvtHdr.fDate");
   b_fTracks_ = fTree->GetBranch("fTracks_");
   b_fTracks_fPx = fTree->GetBranch("fTracks.fPx");
   b_fTracks_fPy = fTree->GetBranch("fTracks.fPy");
   b_fTracks_fPz = fTree->GetBranch("fTracks.fPz");
   b_fTracks_fRandom = fTree->GetBranch("fTracks.fRandom");
   b_fTracks_fMass2 = fTree->GetBranch("fTracks.fMass2");
   b_fTracks_fBx = fTree->GetBranch("fTracks.fBx");
   b_fTracks_fBy = fTree->GetBranch("fTracks.fBy");
   b_fTracks_fMeanCharge = fTree->GetBranch("fTracks.fMeanCharge");
   b_fTracks_fXfirst = fTree->GetBranch("fTracks.fXfirst");
   b_fTracks_fXlast = fTree->GetBranch("fTracks.fXlast");
   b_fTracks_fYfirst = fTree->GetBranch("fTracks.fYfirst");
   b_fTracks_fYlast = fTree->GetBranch("fTracks.fYlast");
   b_fTracks_fZfirst = fTree->GetBranch("fTracks.fZfirst");
   b_fTracks_fZlast = fTree->GetBranch("fTracks.fZlast");
   b_fTracks_fCharge = fTree->GetBranch("fTracks.fCharge");
   b_fTracks_fNpoint = fTree->GetBranch("fTracks.fNpoint");
   b_fTracks_fValid = fTree->GetBranch("fTracks.fValid");
   b_fTracks_fUniqueID = fTree->GetBranch("fTracks.fUniqueID");
   b_fTracks_fBits = fTree->GetBranch("fTracks.fBits");
   b_fH = fTree->GetBranch("fH");
   b_fUniqueID = fTree->GetBranch("fUniqueID");
   b_fBits = fTree->GetBranch("fBits");
}

void SplitClass::Show(Int_t entry)
{
// Print contents of entry.
// If entry is not specified, print current entry
   if (!fTree) return;
   fTree->Show(entry);
}
#endif // #ifdef SplitClass_c
```

24 Quizzes and Answers

Quiz on Root Files

1.What is the value of `gDirectory->pwd()` after this code is executed?

```
root [1] TFile *f1=new TFile("AFile1.root","RECREATE")
root [2] TFile *f2=new TFile("AFile2.root","RECREATE")
root [3] TFile *f3=new TFile("AFile3.root","RECREATE")
root [4] f2->cd()
```

a) `Rint`

b) `AFile1.root`

c) `AFile2.root`

d) `AFile3.root`

2. The `hsimple.root` file contains four histograms: `hpx, hprof, ntuple`, and `hpxpy`. After executing these lines what objects are named when the command `gDirectory->GetList()->Print()` is executed? Hint: the `GetList` command builds a list of "in-memory" objects of the directory.

```
root [0] TFile *f1 = new TFile("hsimple.root","UPDATE");
root [1] gDirectory->GetList()->Print()
```

a) `hpx, hprof, ntuple, hpxpy`

b) None

c) `hpx`

d) `f1`

3. We now add a call to the Draw method as below. What objects are listed by `gDirectory->GetList()->Print() after the Draw command?`

```
root [2] hpx->Draw();
root [3] gDirectory->GetList()->Print()
```

a) `hpx, hprof, ntuple, hpxpy`

b) None

c) `hpx`

d) `f1`

4. Now, we add another Draw command and a Write command. After executing this code, what would you expect the on-disk contents of `f1` to be?

```
root [3] hprof->Draw();
root [4] hprof->Write();
```

a) `hpx;1, hpxpy;1, hprof;1, ntuple;1,`

b) `hpx;2, hpx;1, hpxpy;1, hprof;2, hprof;1, ntuple;1, hpx;1, hprof;1, ntuple;1, c1;1`

c) `hpx;1, hpxpy;1, hprof;2, hprof;1, ntuple;1`

d) `hpx;2, hpx;1, hpxpy;2, hpxpy;1, hprof;2, hprof;1, ntuple;2, ntuple;1,`

e) `hpx;1, hpxpy;1, hprof;2, hprof;1, ntuple;1,c1;1`

f) None of the above

5. After executing this line after the lines in the previous question, what would you expect `f1->ls()` to list?

```
root [5] f1->Write();
```

a) `hpx;1, hpxpy;1, hprof;1, ntuple;1,`

b) `hpx;2, hpx;1, hpxpy;1, hprof;3, hprof;2, hprof;1, ntuple;1, hpx;1, hprof;1, ntuple;1, c1;1`

c) `hpx;2, hpx;1, hpxpy;2, hpxpy;1 hprof;2, hprof;1, ntuple;2, ntuple;1`

d) `hpx;2, hpx;1, hpxpy;1, hprof;3, hprof;2, hprof;1, ntuple;1`

e) `hpx;2, hpx;1, hpxpy;1, hprof;3, hprof;2, hprof;1, ntuple;1`

f) None of the above

6. After this line, what would you expect `gDirectory->ls()` to list?

```
root [6] f1->Close();
```

a) `hpx;1, hprof;1, ntuple;1, hpxpy;1`

b) `hpx;1, hpx;2, hprof;1, hprof;2, ntuple;1, hpxpy;1`

c) `hpx;1, hprof;1, ntuple;1, hpxpy;1, c1;1`

d) `hpx;1, hpx;2, hprof;1, hprof;2, ntuple;1, ntuple;2, hpxpy;1,hpxpy;2`

e) `hpx;1, hpx;2, hprof;1, hprof;2, ntuple;1, ntuple;2, hpxpy;1,hpxpy;2,c1;1`

f) None of the above

Quiz on Streamers

Note that in this quiz more than one answer may be correct. Choose all the choices that apply.

1. A streamers job is to:

a) Write an object to a file

b) Decompose an object into simple data types and write them to a buffer

c) Decompose an object into simple data types and write them to a file

2. A streamer is:

a) Responsible for calling the streamers of all its parents

b) Responsible for calling the streamers of all its object data members

c) Streaming simple data members

d) Responsible for checking the byte count

3. What class contains the `TBuffer` with the streamed object when the object is written to a file in the `TObject::Write` method?

a) The Object's class (i.e. Event)

b) `TKey`

c) `TObject`

4. How would you modify the `EventLinkDef.h` file to let `rootcint` know NOT to generate a streamer for the `EventHeader` class?

```
a) #pragma link C++ class EventHeader*;
b) #pragma link C++ class EventHeader-;
c) #pragma link C++ class EventHeader+;
d) #pragma link C++ class EventHeader;
```

5. How would you modify the `EventLinkDef.h` file to tell `rootcint` to include the byte count check in the automatically generated streamer (in

ROOT version 2.25)?

```
a) #pragma link C++ class EventHeader*;
b) #pragma link C++ class EventHeader-;
c) #pragma link C++ class EventHeader+;
d) #pragma link C++ class EventHeader;
```

6. Assuming the `EventLinkDef.h` file contains this line:

```
#pragma link C++ class EventHeader+;
```

What statements below apply when this call to `ClassDef` is made?

```
ClassDef (Event,0)
```

a) Writes the class version number 0 in the streamer

b) Generates an empty streamer

c) No streamer is generated

d) A streamer with a byte count check is generated

7. Why would you write your own streamer?

a) Because you need to read/write multiple versions of your class

b) Because you have an array of integers data member and an older version of root

c) Because the streamer generated by `rootcint` does not stream the parent classes and your class inherits from multiple classes.

8. How does ROOT react when reading objects without streamers?

a) Using a default streamer

b) Skipping the object by using the byte count

c) Stop reading and print an error message

9. What does the `StreamerInfo` string tell us about the class?

```
"TNamed;TAttLine;TAttFill;TAttMarker;Int_t fScanField;Int_t
fUpdate;Int_t fMaxEntryLoop;Int_t fMaxVirtualSize"
```

a) It inherits from `TObject`

b) It inherits from `TNamed, TAttLine, and TattFill`

c) It has an array of integers.

10. Why do you need to write your own `StreamerInfo` when you have a customized streamer?

a) Because ROOT will give a segmentation fault if you don't

b) Because ROOT will otherwise generate an empty string

c) Because the string needs to match the order and contents of what is streamed out in the streamer method.

Quiz on Trees

1. We have a class called Event with these data members:

```
class Event : public TObject {
      Int_t          fNtrack;
      Int_t          fNseg;
      Float_t        fTemperature;
      EventHeader    fEvtHdr;
      TClonesArray  *fTracks;

class Track : public TObject {
      Int_t          Px;
      Int_t          Py;
      Float_t        Pz;
```

Creating a branch with this call, how many branches will be crated?

```
Event *event = new Event();
tree->Branch("EventBranch", "Event", &event);
```

a) 1

b) 5

c) 6

d) 7

e) Error

2. With this command, how many branches will be created?

```
Event *event = new Event();
tree->Branch("EventBranch", "Event", &event, 64000,0);
```

a) 0

b) 1

c) 4

d) 5

e) 6

f) Error

3. With this command, how many branches will be created?

```
Event *event = new Event();
tree->Branch("EventBranch", "Event", event, 64000,1);
```

a) 0

b) 1

c) 4

d) error

4. How many branches will this tree have?

```
tree->Branch ("Ev_Branch",&event,
"ntrack/I2:nseg:nvtex:flag/i:temp/F");
```

a) One branch, with five leaves

b) Five branches with one leaf each

c) No branch, no leaves

d) Error

5. What type of leaves is on the branch of the tree above?

a) 3- 32 bit signed integer, 1- 32 bit unsigned integer, 1- 32 bit floating point number.

b) 1- 16 bit signed integer, 3- 32 bit unsigned integer, 1- 32 bit floating point number.

c) 1- 32 bit signed integer, 3- 32 bit unsigned integer, 1- 32 bit floating point number.

d) 3 - 16 bit signed integer, 1- 32 bit unsigned integer, 1 - 32 bit floating point number.

6. Assuming we have a structure defined below:

```
typedef struct {
      Int_t a,b,c;
      Float_t p;
} MyStructure;
MyStructure mst;
```

How many branches and what type of leaves will this call to `Branch` create?

```
tree->Branch ("ABranch",&mst,"b/i:c:p/F");
```

a) One Branch with three leaves: two integers and one float.

b) Three branches with one leaf each. One integer, and two floats.

c) One branch with three leaves: one integer and two floats.

7. In the question above, what variable in the structure will be in the leaf called "b"?

a) `mst.a`

b) `mst.b`

c) `mst.c`

d) `mst.p`

8. Which of the cases below are candidates for a branch of `TClonesArrays`:

a) An array of events

b) An array of tracks for one event

c) An array of hits for one event

Answers to Quiz on ROOT Files

1. C - is correct. The last command sets the current directory to f2, which is AFile2.root.

2. B - is correct. At this time, there are no objects in memory. The list that `gDirectory->GetList()` returns is empty.

3. C - is correct. The call to the Draw method brought the object `hpx` into memory.

4. C - is correct. The call `hprof->Write()` added another version of `hprof` to the file. It did not add anything else.

5. E - is correct. The `f1->Write()` command added yet another `hprof` object and a hpx object to the file.

6. F- is correct. After the file is closed, `gDirectory` no longer points to it.

Answers to Quiz on Streamers

1. B is correct. The streamer does not write the buffer or the object to a file. It only streams the object into the buffer.

2. A, B, C, and D are correct.

3. B is correct. `TObject::Write` creates a `TKey`, which has a buffer

4. B is correct

5. C is correct

6. B is correct. The zero in the version parameter is a special case and instructs CINT to generate an empty streamer.

7. A and B are correct.

8. B is correct

9. B is correct

10. C is correct

Answers to Quiz on Root Trees:

1. D - is correct. The branch is split by default to one branch for each member function. The split is recursive, so the track in the clones array is also split into one branch per data member of the track class. Thus the total number of branches is 7.

2. B - is correct. The split-level is 0 and there is only one branch with one leaf of type Event created.

3. D - is correct. The third parameter is not a pointer to an Event object, not the address of a pointer.

4. A- is correct. The second parameter is the description of the leaf list in the branch.

5. D - is correct. The type qualifier "I2" means a signed integer that is 2 bytes (i.e. 16 bits" long. When no type is given as in `nseg` and `nvtex` the type of the previous leaf is assumed.

6. A - is correct.

7. A - is correct. The second parameter is the address of the first leaf. The address in this statement is of the first variable in the structure which is "a". The leaf list string names the first leaf b. Hence the value a will be in the leaf b.

8. B and C. Both of these cases are an array per entry.

25 Index

A

B

C

D

E

F

G

H

I

K

L

M

N

O

P

U

W

X

Z